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<b>(54) Title:</b> METHOD FOR INDUCING A CELL-MEDIATED IMMUNE RESPONSE AND PARENTERAL VACCINE FORMULATIONS THEREFOR		
<b>(57) Abstract</b>  A method of inducing either a T <sub>H</sub> 1 polarised immune response, a T <sub>H</sub> 2 polarised immune response or a combined T <sub>H</sub> 1 and T <sub>H</sub> 2 response to an antigen and associated vaccine formulations are disclosed. A method is provided for inducing a polarised T <sub>H</sub> 1 response by parenteral administration of microparticles sized such that at least 50 % of the microparticles are less than 5 µm, the microparticles containing antigen entrapped or encapsulated by a biodegradable polymer. Additionally, a method is provided for inducing a polarised T <sub>H</sub> 2 response by parenteral administration of nanoparticles sized such that at least 50 % of the nanoparticles are less than 600 nm, the nanoparticles containing antigen entrapped or encapsulated by a biodegradable polymer. Vaccine formulations containing the <i>B.pertussis</i> antigens PTd, FHA or a combination of PTd and FHA are provided.		

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## Description

METHOD FOR INDUCING A CELL-MEDIATED IMMUNE RESPONSE AND PARENTERAL VACCINE FORMULATIONS THEREFOR

### Technical Field

5           The present invention relates to vaccine formulations and to methods for inducing an immune response that is polarised in favour of either a cell-mediated  $T_H1$  immune response, a humoral  $T_H2$  immune response or a combined  $T_H1$  and  $T_H2$  response. In particular, the present invention relates to parenteral microparticulate and nanoparticulate  
10 vaccine formulations comprising antigens entrapped or encapsulated within polymer particles.

### Background Art

Controlled release antigen delivery systems have attracted considerable interest in the continuing search for vaccine carriers. The  
15 effectiveness of polymer matrices in the sustained release of antigen was first demonstrated in 1979 with the entrapment of bovine serum albumin in a non-degradable ethylene-vinyl acetate copolymer pellet for subcutaneous implantation [Preis *et al.*, *J. Immunol. Methods* **28**, 193–197 (1979)]. This composition induced an antibody response for six  
20 months after administration and gave antibody levels similar to two injections of the same total amount of antigen in complete Freund's adjuvant.

More recently aluminium salts (*see* for example WO 94/15636 (CSL Ltd.)) and biodegradable polymers such as poly (L-lactide)

(hereinafter PLA) and poly (DL-lactide-*co*-glycolide) (hereafter PLGA) have been used as carriers for vaccine antigens. WO 95/11008 (Genentech Inc.) discloses the use of PLGA microspheres for encapsulating an antigen in which the ratio of lactide to glycolide in the microspheres ranges from 100:0 to 0:100 weight percent, the inherent viscosity of the PLGA polymers ranges from 0.1 - 1.2 dl/g and the median diameter of the microspheres ranges from 20 - 100  $\mu$ m. The antigen can be continuously released from the microspheres over an extended period in a triphasic pattern. A method for encapsulating antigens in microspheres is also disclosed.

Eldridge *et al.*, *J. Controlled Release* **11**, 205-214 (1990) report that the oral administration of biodegradable PLA or PLGA microspheres containing the staphylococcal enterotoxin B (SEB) vaccine are absorbed into the Peyer's patches of the small intestine. Uptake is restricted to particles  $\leq 10 \mu$ m in diameter. The majority of microspheres  $< 5 \mu$ m were observed to be transported to systemic lymphoid tissue (such as the spleen) where the released antigen stimulated a serum antibody response. The majority of those particles  $> 5 \mu$ m were found to be retained in the Peyer's patches. EP 0 266 119 (The UAB Research Foundation & Southern Research Institute) teaches an oral composition comprising a bioactive agent, such as an antigen, encapsulated in a biodegradable polymer excipient to form a microcapsule less than or equal to  $10 \mu$ m that is capable of being taken up selectively by the Peyer's patch. Similarly, EP 0 333 523 (The UAB Research Foundation & Southern Research Institute) and EP 0 706 792 divided therefrom, teach compositions for delivery of a bioactive agent,

such as an antigen, to the mucosally associated lymph tissue (MALT), comprising microcapsules having sizes between 1-5 and 5-10  $\mu\text{m}$  for selective absorption and retention in MALT.

EP 0 686 030 (Gesellschaft zur Forderung der  
5 Industrieorientierten Forschung) teaches a method of potentiating an immune response by embedding a model antigen in a biodegradable biopolymer and injecting it in the form of a dispersion in order to trigger a humoral and cellular response. In this instance PLGA entrapped antigens were shown to elicit long lasting T helper, antibody and  
10 cytotoxic T cell responses.

Moore *et al.*, *Vaccine* **18** 1741-1749 (1995) discloses that HIV gp120 entrapped in PLGA solvent evaporated microspheres can induce cytolytic activity (CTL) in mice splenic T cells upon nasal, s.c. or i.p. administration. For this antigen, anti-HIV specific CD4+ and CD8+ T  
15 cells were induced leading to induction of  $T_H1$  cells and CTL respectively. In the case of i.p. ovalbumen (OVA) immunisation, Maloy *et al.*, *Immunology* **81**, 661-667 (1994) disclose that a single s.c. immunization with OVA-PLGA microspheres primed significant OVA-specific responses and strong OVA-specific CTL responses were found  
20 after i.p immunisation in mice. Newman *et al.*, *J. Controlled Release*, **54**, 49-59 (1998) disclose the use of OVA peptide encapsulated in PLGA microspheres for inducing a  $T_H1$  type immune response in mice after s.c. delivery.

Distinction between the types of immune response in terms of  $T_H1$   
25 (cell-mediated) and  $T_H2$  (humoral / antibody) type responses is important for protection against infectious diseases induced by intracellular

pathogens or extracellular toxins respectively. The division of CD4+ lymphocytes into T<sub>H</sub>1 and T<sub>H</sub>2 according to antibody sub-class and cytokine profile has led to attempts to classify adjuvants accordingly. For instance, aluminium hydroxide (also referred to as alum) is  
5 considered to have a higher capacity for inducing T<sub>H</sub>2 rather than T<sub>H</sub>1 immunity [see, e.g., Men *et al.*, *Vaccine* **13**, 683-689 (1995)]. US 5,417,986 (US Army) describes the loading of PLGA microspheres with antigens such as CFA (complete Freund's adjuvant) and HepB sAg (hepatitis B surface antigen) and injected to give both antibodies and T  
10 cell proliferation in animals.

Review of the above cited references and other literature in the area shows that there is no general method for predicting or anticipating the nature of the immune response induced by an antigen in combination with a given adjuvant.

15 With respect to *Bordetella pertussis*, the fimbriae, filamentous hemagglutinin (FHA), inactivated pertussis toxin (PTd) and pertactin antigens have all been entrapped in PLGA microspheres, administered individually by a variety of routes and have been shown to protect against infection in response to challenge in a mouse model of *pertussis*  
20 (see, e.g., Shahin *et al.*, *Infection and Immunity* **63**, 1195-1200 (1995); Jones *et al.*, *Infection and Immunity* **64**, 489-494 (1996); Cahill *et al.*, *Vaccine* **13**, 455-462 (1995)). WO 93/21950 (Roberts and Dougan) teaches that the antigens FHA and pertactin are immunogenic as a mixture or when entrapped in PLGA and delivered to mucosal sites.  
25 Singh *et al.*, *Vaccine* **16**, 346-352 (1998) describe that two antigens entrapped simultaneously in the same polymer particles can induce

antibody responses to each agent in rats after parenteral delivery. There is evidence that the mouse model of aerolised *pertussis* infection correlates with *pertussis* vaccine efficacy in children [Mills *et al.*, *Infection and Immunity* 66, 594-602 (1998)] and that T<sub>H</sub>1 cells play an  
5 important role in bacterial clearance [Mills *et al.*, *Infection and Immunity* 61, 399-410 (1993)]. Further work by Ryan *et al.*, *Immunology* 93, 1-10 (1998) indicates that the long-term protective immunity of a potent whole cell *pertussis* vaccine in children is largely mediated by T<sub>H</sub>1 cells. Acellular *pertussis* vaccines appear to involve a mixed population of T<sub>H</sub>1  
10 and T<sub>H</sub>2 cells and their long term efficacy is unknown.

Despite the abovementioned prior art, the ability to predict and control the type of immune response produced by a given vaccine formulation remains a goal central to immunology research. This is particularly true given the variation from disease to disease of the  
15 relative importance of T<sub>H</sub>1 and T<sub>H</sub>2 components of the immune response. For example, T<sub>H</sub>1 response can assist in cytotoxic T cell activity which is important in clearances of viruses, intracellular pathogens and some cancers.

Therefore, it is an object of the present invention to provide a  
20 vaccine formulation which will elicit a significant and reproducible polarised T<sub>H</sub>1 immune response *in vivo*.

It is also an object of this invention to provide methods to enhance the T<sub>H</sub>1 T cell response compared to the T<sub>H</sub>2 response.

Additionally, it is an object of the present invention to provide a  
25 vaccine formulation which will elicit a significant and reproducible

polarised  $T_H2$  immune response *in vivo* and methods to enhance the  $T_H2$  T cell response compared to the  $T_H1$  response.

It is another object of the present invention to provide a parenteral vaccine formulation directed at a particular agent such as an infectious agent which, after administration to the subject, is capable of providing protective immunity against the agent.

Further objects of the present invention include an improved composition for use in the preparation of a *B. pertussis* vaccine and a method for the vaccination against *B. pertussis*.

#### 10 Disclosure of Invention

It has now been surprisingly found that polarisation of the  $T_H1$  immune response over the  $T_H2$  immune response or that polarisation of the  $T_H2$  immune response over the  $T_H1$  immune response can be induced by the choice of parenteral administration of microparticles or nanoparticles comprising antigen entrapped or encapsulated in a biodegradable polymer using a suitable combination of polymer type, loading method, morphology and size.

Furthermore, it has been found that a vaccine formulation designed for a particular agent such as an infectious agent and containing microparticles or nanoparticles comprising antigen entrapped or encapsulated in a biodegradable polymer can, in addition to inducing T cell proliferation, yield protective immunity against the infectious agent.

Accordingly, the present invention provides a method of inducing a  $T_H1$  polarised immune response to an antigen(s), comprising



parenterally administering to a subject, such as a mammal and preferably a human, microparticles sized such that at least 50% of the microparticles are less than 5  $\mu\text{m}$ , preferably less than 3  $\mu\text{m}$ , the microparticles comprising the antigen(s) entrapped or encapsulated by a biodegradable polymer. A vaccine formulation for parenteral  
5 administration comprising microparticles sized such that at least 50% of the microparticles are less than 5  $\mu\text{m}$ , preferably less than 3  $\mu\text{m}$ , the microparticles comprising antigen entrapped or encapsulated by a biodegradable polymer is also provided.

10 Additionally, the present invention provides a method of inducing a  $T_H2$  polarised immune response to an antigen(s), comprising parenterally administering to a subject, such as a mammal and preferably a human, nanoparticles such that at least 50% of the nanoparticles are less than 600 nm, preferably less than 500 nm, the nanoparticles  
15 comprising the antigen(s) entrapped or encapsulated by a biodegradable polymer. A vaccine formulation for parenteral administration comprising microparticles sized such that at least 50% of the nanoparticles are less than 600 nm, preferably less than 500 nm, the nanoparticles comprising antigen entrapped or encapsulated by a  
20 biodegradable polymer is also provided.

The present invention also provides a method of inducing both a potent  $T_H1$  and  $T_H2$  immune response to an antigen(s), comprising parenterally administering to a subject, such as a mammal and preferably a human, (1) microparticles sized such that at least 50% of the  
25 microparticles are less than 5  $\mu\text{m}$ , preferably less than 3  $\mu\text{m}$ , the microparticles comprising the antigen(s) entrapped or encapsulated by a

biodegradable polymer in combination with (2) antigen(s) presented so as to produce an immune response polarised in favor of a  $T_H2$  response. To produce an immune response polarised in favor of a  $T_H2$  response, the antigen(s) can be presented as nanoparticles sized such that at least 5 50% of the nanoparticles are less than 600 nm, preferably less than 500 nm, the nanoparticles comprising the antigen(s) entrapped or encapsulated by a biodegradable polymer; as soluble antigen(s); and/or as antigen(s) adsorbed or presented at least in part on the surface of a particle. The administration of the antigen-containing microparticles in 10 combination with the antigen presented so as to produce an immune response polarised in favor of a  $T_H2$  response can be simultaneous, separate, or sequential. A vaccine formulation for parenteral administration comprising antigen entrapped or encapsulated microparticles in combination with antigen presented so as to produce an 15 immune response polarised in favor of a  $T_H2$  response such as antigen entrapped or encapsulated nanoparticles is also provided.

The present invention also provides a method of providing protective immunity against *B. pertussis*, comprising parenterally administering to a subject microparticles sized such that at least 50% of 20 the microparticles are less than 5  $\mu\text{m}$ , preferably less than 3  $\mu\text{m}$ , the microparticles comprising at least one *B. pertussis* antigen entrapped or encapsulated by a biodegradable polymer. The present invention also provides a method of providing protective immunity against *B. pertussis*, comprising parenterally administering to a subject nanoparticles sized 25 such that at least 50% of the nanoparticles are less the 600 nm, preferably less than 500nm, the nanoparticles comprising at least one *B. pertussis* antigen entrapped or encapsulated by a biodegradable polymer.

Additionally, the present invention provides a method of providing protective immunity against *B. pertussis*, comprising parenterally administering to a subject microparticles sized such that at least 50% of the microparticles are less than 5  $\mu\text{m}$ , preferably less than 3  $\mu\text{m}$ , the  
5 microparticles comprising at least one *B. pertussis* antigen entrapped or encapsulated by a biodegradable polymer in combination with at least one *B. pertussis* antigen presented so as to produce an immune response polarised in favor of a  $T_H2$  response, such as at least one *B. pertussis* antigen presented as nanoparticles sized such that at least 50% of the  
10 nanoparticles are less than 600 nm, preferably less than 500 nm, the nanoparticles comprising the at least one *B. pertussis* antigen entrapped or encapsulated by a biodegradable polymer; as soluble *B. pertussis* antigen; and/or as *B. pertussis* antigen absorbed or presented at least in part on the surface of a particle.

15 Preferably, the antigen is capable of eliciting an immune response upon administration, the antigen being entrapped and / or encapsulated within a biocompatible, biodegradable polymer carrier material. Routes for parenteral administration include intraperitoneal (i.p.), subcutaneous (s.c.) and intramuscular (i.m.) routes of administration. Preferably, the  
20 method for entrapping and / or encapsulating the antigen within the polymer carrier material is a solvent evaporation based process for formation of antigen entrapped or encapsulated in microparticles or a coacervation based process for formation of antigen entrapped or encapsulated in nanoparticles.

25 The present invention further relates to a method for the prevention of *B. pertussis* which method comprises eliciting a  $T_H1$

immune response by the administration of a composition comprising inactivated *B. pertussis* toxin and/or FHA encapsulated in poly (DL-lactide-co-glycolide) microparticles, wherein encapsulation of the inactivated *B. pertussis* toxin and/or FHA in poly (DL-lactide-co-glycolide) particles is carried out by solvent evaporation and wherein administration is by way of parenteral injection.

Additionally, the present invention further relates to a method for the prevention of *B. pertussis* which method comprises eliciting a  $T_H2$  immune response by the administration of a composition comprising inactivated *B. pertussis* toxin and/or FHA encapsulated in poly (DL-lactide-co-glycolide) nanoparticles, wherein encapsulation of the inactivated *B. pertussis* toxin and/or FHA in poly (DL-lactide-co-glycolide) particles is carried out by coacervation and wherein administration is by way of parenteral injection.

#### Brief Description of Drawings

Figure 1 shows the  $T_H1/T_H2$  responses following parenteral immunisation with KLH entrapped in PLGA. Four groups of 4 mice received i.p. inoculations with 5.0  $\mu$ g of KLH encapsulated in PLGA microparticles (KLH-PLGA), adsorbed to alum (KLH-alum) or in solution combined with empty PLGA microparticles (KLH + PLGA). Mice were immunised twice (0 and 4 weeks) and sacrificed two weeks later. Spleen cells from individual mice were stimulated with 0.03 – 20  $\mu$ g/ml of KLH or with medium alone. After 3 days culture supernatants were tested for IL-5 and IFN- $\gamma$  by specific immunoassays. Each bar

represents the mean response for 4 mice in each group. Note the difference in the scale for IL-5 (pg/ml) and IFN- $\gamma$  (ng/ml);

Figure 2 shows the T<sub>H</sub>1/T<sub>H</sub>2 responses following parenteral immunisation with PTd-PLGA microparticles (batch PTd-1 of Example 2) prepared by solvent evaporation. Three groups of mice received a single dose of 5  $\mu$ g PTd-PLGA, PTd with alum or in solution in PBS. The levels of IFN- $\gamma$  and IL-5 were determined by specific immunoassays in cultured spleen cells three days after stimulation with PT. Medium = negative control; iPT = inactivated PT; B pertussis = active pertussis bacteria and anti-CD3/PMA = the positive control anti-CD3 antibody/phorbol 12-myristate-13 acetate;

Figure 3 shows a plot of Log<sub>10</sub> CFU counts *per lung versus* Days after challenge for the control group (immunised with empty PLGA microparticles), PTd +FHA +alum group (immunised with 5 $\mu$ g each of PTd and FHA adsorbed onto alum) and PTd + FHA in PLG group (immunised with 5 $\mu$ g each of PTd and FHA entrapped in PLGA microparticles according to Examples 2 and 3) for the challenge study in balb/c mice described in Example 7;

Figure 4 shows the serum antibody titres to PTd following i.p. administration as described in Example 7 of PTd + FHA in PLGA (5  $\mu$ g each of PTd and FHA entrapped in PLGA microparticles according to Example 2 and 3); PTd + FHA + alum (5  $\mu$ g each of PTd and FHA adsorbed onto alum; and PLGA (i.p.) (empty PLGA microparticles) to balb/c mice;

Figure 5 compares the  $T_H1/T_H2$  responses following parenteral immunisation of balb/c mice with PTd + FHA in PLGA (5 $\mu$ g each of PTd and FHA entrapped in PLGA microparticles according to Example 2 and 3; 4 animals) and PTd + FHA + alum (5  $\mu$ g each of PTd and FHA adsorbed onto alum; 4 animals). The levels of IFN- $\gamma$  and IL-5 were determined by specific immunoassays in cultured spleen cells three days after stimulation with PT. iPT = inactivated PT; FHA = filamentous haemagglutinin; B pertussis = active pertussis bacteria and anti-CD3/PMA = the positive control anti-CD3 antibody/phorbol 12-myristate-13 acetate;

Figure 6 shows the  $T_H1/T_H2$  responses following i.p. administration of low dose (1  $\mu$ g) FHA encapsulated in PLGA. Spleen cells from individual mice were stimulated with medium alone (0), inactivated PT (PT), filamentous haemagglutinin (FHA), active pertussis bacteria (BP) and the positive control anti-CD3 antibody / phorbol 12-myristate-13 acetate (PMA/CD3);

Figure 7 shows a plot of Log<sub>10</sub> CFU counts *per lung versus* Days after challenge for the control group (immunised with empty PLGA microparticles), PTd-PLG group (immunised with 1 $\mu$ g of PTd entrapped in PLGA microparticles), PTd/FHA-alum group (immunised with 1 $\mu$ g each of PTd and FHA adsorbed onto alum), FHA-PLG (immunised with 1  $\mu$ g of FHA entrapped in PLGA microparticles) and PTd/ FHA-PLG group (immunised with 1 $\mu$ g each of PTd and FHA entrapped in PLGA microparticles) for the low dose challenge study in balb/c mice described in Example 8;

Figure 8 shows a plot of Log<sub>10</sub> CFU counts *per lung versus* days post challenge for the control group (immunised with empty PLGA microparticles), PTd/FHA-alum group (immunised with 5 µg each of PTd and FHA adsorbed onto alum), and PTd/ FHA-PLG group  
5 (immunised with 5 µg each of PTd and FHA entrapped in PLGA microparticles) for the delayed challenge study in balb/c mice described in Example 9;

Figure 9 shows the T<sub>H</sub>1 response (IFN-γ) and the T<sub>H</sub>2 response (IL-5) following i.m. immunisation with Treatment F of Example 10.  
10 The levels of IFN-γ and IL-5 were determined by specific immunoassays in cultured spleen cells from 5 animals (Mouse 1 through Mouse 5) three days after stimulation with PT. BG = negative control; PT = inactivated PT; B. pert = active pertussis bacteria and PMA/a-CD3 = the positive control anti-CD3 antibody/phorbol 12-myristate-13 acetate; and

15 Figure 10 shows the T<sub>H</sub>1/T<sub>H</sub>2 responses following parenteral immunisation with coacervated nanoparticulate Treatments A-F of Example 11. The levels of IFN-γ and IL-5 were determined by specific immunoassays in cultured spleen cells three days after stimulation with PT. iPT-1 = inactivated PT (1.0µg/ml); iPT-5 = inactivated PT (5.0  
20 µg/ml); FHA-1 = FHA (1.0 µg/ml); FHA -5 = FHA (5.0 µg/ml); BP = active pertussis bacteria and PMA/CD3 = the positive control anti-CD3 antibody/phorbol 12-myristate-13 acetate.

While vaccine formulations which comprise antigens loaded onto polymer particles are known in the prior art it has now been found that  
25 the choice of biocompatible carrier material, the method of loading of

the biologically active agent (i.e., the method for adsorbing and / or encapsulating the biologically active agent onto and / or within the biocompatible, biodegradable polymer material), the size of the particles and/or the route of administration are all contributing factors in  
5 determining the nature of the immune response produced. By a suitable combination of the above listed determinants a composition may be prepared which elicits a particular polarised immune response. Polarisation of the immune response may be characterised by determination of the relative proportions of  $T_H1$  and  $T_H2$  indicators,  
10 typically cytokines such as IFN- $\gamma$ , TNF, IL-2 or IL-12 and IL-5, IL-4, IL-6 or IL-10 specific to  $T_H1$  and  $T_H2$  responses, respectively.

It has now been found that polarisation of the  $T_H1$  immune response over the  $T_H2$  immune response can be induced by parenteral administration of appropriately sized antigen-loaded microparticles and  
15 that polarisation of the  $T_H2$  immune response over the  $T_H1$  immune response can be induced by parenteral administration of appropriately sized antigen-loaded nanoparticles. While not wishing to be limited by any theory of the mechanism behind this differentiation, it is possible that the different polarization obtained from administration of antigen  
20 entrapped microparticles and antigen entrapped nanoparticles may relate to the physical positioning of the antigen. For instance, some antigen may be presented on the exterior of the nanoparticles compared to relatively more antigen entrapped within the microparticles. Support of a relationship between  $T_H2$  polarisation and externally associated antigen  
25 can be found from data showing a  $T_H2$  polarisation following presentation of soluble antigen, such as that presented in Example 5



below (administration of soluble antigen in combination with empty microparticles).

Preferable routes for parenteral administration include i.p, i.m., and s.c., most preferably i.p. and i.m.

5           Biologically active agents suitable for the practice of the present invention are typically antigens capable of eliciting a polarised  $T_H1$  immune response (e.g., viral antigens, cancer antigens, allergens etc.), a polarized  $T_H2$  response (e.g., toxoid antigens, parasite antigens etc.) or a mixed  $T_H1/T_H2$  response upon administration. Preferred antigens  
10   include those selected from the list comprising of PTd, inactivated pertussis toxin or pertactin; FHA, filamentous hemagglutinin; TT, tetanus toxoid; HIV gp-120; hepatitis B surface antigen; DT, diphtheria toxoid; HSV, herpes simplex type 1; HPV, human papilloma virus; polio; influenza epitopes; *H. pylori*; shigella; chlorea; salmonella; rotavirus;  
15   RSV, respiratory virus; yellow fever; hepatitis A and C; meningococcal types A - C; pneumococcal; parasites such as leishmania; mycobacteria such as tuberculosis; and cancer vaccine antigens

As used herein, the term "protective immunity" refers to at least 75% clearance, more preferably 90% clearance of the challenging agent,  
20   such as an infectious agent, from the subject preferably within 2 weeks after the introduction of the challenging agent, more preferably within 1 week, most preferably within 3 days.

As used herein, the term "pharmaceutically effective amount" refers to the amount of antigen required to elicit a protective immunity  
25   response to that antigen. For instance, in mice, protective immunity is

achieved with an amount of a *B. pertussis* antigen(s) in the 1-5 µg range for each antigen given parenterally in multiple doses, such as two doses, or in a single dose.

As used herein, references to the sizes of microparticles and/or  
5 nanoparticles refer to sizes as determined by visual assessment of scanning electron micrographs and/or, where indicated, laser light diffractometry.

It has been found that the choice of biocompatible, biodegradable polymer material used as a carrier for entrapping or encapsulating the  
10 antigen, the size of the resulting particles and/or the method of loading the carrier with antigen are important in defining the nature of immune response achieved. Preferably the biocompatible, biodegradable polymer material is a copolymer of lactic acid and glycolic acid, such as 50:50 poly (D,L-lactide-co-glycolide), poly (lactide-co-glycolide), and  
15 enantiomers thereof or a polymer of lactic acid, such as poly (lactide) and enantiomers thereof. The antigen can be loaded by a solvent evaporation type process, a coacervation process or a spray drying process, preferably by a solvent evaporation type process or a coacervation method. Further details of the loading processes are given  
20 in the Examples below.

#### Modes for Carrying Out the Invention

As will be further appreciated from the examples below the nature of the immune response elicited by antigen loaded polymer particles does not depend on a single factor, but is governed by a combination of a  
25 number of factors.

### *Examples*

All percentages are by weight (w/w) unless other wise stated. The following abbreviation are used throughout the examples: KLH, keyhole limpet hemacyanin; PTd, inactivated pertussis toxin; FHA, filamentous hemagglutinin; PLA, poly lactide; PLGA, poly lactide-co-glycolide; 5 DCM, dichloromethane; PVA, poly vinyl alcohol; PBS, phosphate buffer solution.

#### Example 1

##### Preparation of KLH-PLGA microparticles using a solvent evaporation 10 method.

A polymer solution of PLGA [poly (D,L-lactide-co-glycolide), 50:50; i.v. = 0.94 dl / g; supplied by Boehringer Ingelheim] in dichloromethane (10 % PLGA in 10 ml DCM) was prepared two hours prior to use and subsequently chilled 30 minutes prior to use. The antigen, KLH (supplied by Calbiochem as a powder), was prepared as an 15 aqueous solution (5.1 mg KLH in 1 ml water) containing 2 % PVA. A first water-in-oil emulsion was prepared by adding the antigen solution to the polymer solution and homogenising for 1 min. at 24,000 rpm on ice. This first emulsion was poured slowly into an aqueous solution of 20 PVA (40 ml, 3 % PVA) forming a second water-oil-water emulsion and homogenisation was continued for 2 min. with a 15 sec. break [1 min.; 15 sec. break; 1 min.]. The resulting emulsion was stirred for 2 hours to evaporate the dichloromethane. The antigen-loaded particles (75% yield) were collected by centrifugation (10,000 rpm for 15 min).

The morphology and the particle size of the KLH-PLGA particles were examined by scanning electron microscopy (SEM) using a Leica Cambridge S360. Samples were mounted on stubs, gold coated and scanned at magnifications of x3,000 - 10,000. Particle size assessment  
5 by SEM was carried out by dividing the micrographs at the 5,000 or 10,000 magnification into different fields and counting the number of particles greater and less than 3 microns and 5 microns. Particle size determination was also carried out by laser diffractometry using a Malvern Mastersizer S Ver. 2.14. The microparticles were suspended in  
10 filtered 0.1 % Tween 20, sonicated for 5 minutes and analysed with continuous stirring. KLH-PLGA particles prepared as detailed above were found to have a smooth spherical appearance and a D50% of 2.5  $\mu\text{m}$  by laser light diffraction. By SEM, it could be seen that at least 50 % of the particles had a diameter less than 5 microns.

15 The loading of microparticles with antigen was determined by digesting 10 mg of loaded microparticles in 3 ml of 5 % SDS / 0.1 M NaOH for up to 60 hours with continuous shaking at room temperature. The particles were completely digested during this period. The pH of the solution was adjusted to pH 11.2 with 0.1 M HCl and protein content  
20 was determined using a Bicinchoninic acid (BCA) protein assay kit. Equivalent control particles containing no antigen were also digested. The loading was calculated as follows:

$$\text{Actual loading } (\mu\text{g/mg}) = \frac{\text{concentration in sample } (\mu\text{g/ml}) \times \text{total volume digested (ml)}}{\text{weight of particles (mg)}}$$

25

$$\% \text{ entrapment efficiency} = \frac{\text{actual loading } (\mu\text{g/mg}) \times 100}{\text{theoretical loading } (\mu\text{g/mg})}$$

where the theoretical loading is calculated from the amount of antigen added to the formulation divided by the amount of polymer used.

KLH-PLGA particles prepared according to the present example were  
5 found to have a loading of 3.1  $\mu\text{g}$  antigen / mg particles, giving an entrapment efficiency of 94 %.

The *in vitro* release of antigen from the loaded particles was determined as follows: antigen loaded microparticles and control microparticles (prepared in a similar manner, but containing no antigen)  
10 were accurately weighed and dispersed in PBS containing 0.02 % sodium azide as a bacteriostatic agent. Samples were immersed in a water bath at 37 °C and shaken continuously. At appropriate time intervals, 2.2 ml aliquots were removed with a syringe, filtered and the protein content measured in duplicate by BCA assay. KLH-PLGA  
15 particles prepared according to the present example were found to release 80 % of loaded antigen after 1 hour and 100 % of loaded antigen after 24 hours.

The procedure detailed above was repeated to form a second batch of KLH-PLGA microparticles. This second batch of microparticles  
20 appeared smooth and spherical under SEM with at least 50 % of the particles less than 5 microns, the D50% was determined to be 2.2  $\mu\text{m}$ ; the loading was found to be 3.5  $\mu\text{g}/\text{mg}$  representing 94 % entrapment efficiency; and 76 % of the antigen was determined to be released after 1 hour, with 90 % being released after 24 hours.

Antigen loaded microparticles obtained from these two batches were pooled together for an immunogenicity study in mice as discussed in Example 5 below.

### Example 2

#### 5     Preparation of PTd-PLGA microparticles using a solvent evaporation method.

Using a method substantially the same as that described in Example 1 above, PTd (supplied by Katetsuken) loaded PLGA particles were prepared. The polymer solution was 6.7 % PLGA in 15 ml DCM  
10    and the antigen solution was 744 µg PTd in 2 ml water containing 0.9 % PVA. The first water-in-oil emulsion was poured into 80 ml aqueous PVA (3 % PVA) to form the water-oil-water emulsion. The emulsion was left over night to evaporate the DCM. After collection (88% yield), the microparticles were washed with chilled autoclaved water (30 ml).

15       Characterisation of these particles, identified as PTd-1 in Table 1 below, showed that the microparticles formed were smooth and spherical in appearance with at least 50 % of the particles less than 5 microns in diameter. Laser light diffractometry showed that the particles had a D50% of 2.5 µm. The microparticles were loaded with antigen at 0.12  
20    µg/mg, representing an entrapment efficiency of 15 %.

The *in vitro* release of PTd loaded microparticles was determined according to the following method: 30 mg of microparticles were dispersed in PBS (4.0 ml) containing 0.02 % sodium azide. The sample was placed in a water bath at 37°C and shaken continuously. At

appropriate time intervals the sample was removed from the water bath and centrifuged to pellet the particles. The supernatant was removed and the protein content was determined in duplicate. Three ml of fresh PBS was added to the microparticles to maintain sink conditions and the incubation was continued. PTd-PLGA particles prepared according to the present example (PTd-1) were found to release 22 % of loaded antigen after 1 hour and 56 % of loaded antigen after 24 hours followed by biphasic release over 20 days.

Additional batches of PTd-PLGA microparticles were made following substantially the same procedure as given above using quantities of the various components as summarised in Table 1 below. In batches PTd-2 through PTd-6, no PVA was added to the initial antigen solution and 40 ml chilled autoclaved water was used to wash the recovered microparticles. In each case the resulting antigen loaded microparticles were found to be smooth and spherical in appearance with at least 50 % of the particles less than 5 microns in diameter.

Table 1										
Batch No.	PTd (µg)	Aq. Vol (ml)	% PLG A	DC M (ml)	3% PVA (ml)	Load (µg/mg)	% EE	D50 % (µm)	1 hr (%)	24 hr (%)
PTd-1	744	2	6.7	15	80	0.12	15	2.5	22	56
PTd-2	1536	1.0	4	10	40	1.2	31	3.0	30	
PTd-3	2760	1.5	4	20	80	1.3	33	3.3	.	.
PTd-4	313	1.5	4	20	80	1.3	34	2.4	.	.

	0									
PTd-5	214 0	2.0	4	20	80	1.1	42	3.2	*	*
PTd-6	-	-	-	-	-	-	-	-	17	21

3% PVA is the volume of PVA solution to which the antigen / PLGA water-in-oil emulsion is added; Load is the antigen loading of the microparticles; %EE is the % entrapment efficiency; D50% is the average diameter of the microparticles; 1 hr is the antigen released after 1 hour; 24 hr is the antigen released after 24 hours. \*The loaded microparticles obtained from PTd3, PTd-4 and PTd-5 were pooled for antigen release assay and i.p. protection study (see Example 7 below).

### Example 3

#### 10 Preparation of FHA-PLGA microparticles using a solvent evaporation method.

A procedure substantially similar to that used in Example 2 was employed for the preparation of FHA-loaded PLGA microparticles. Two batches of FHA-PLGA microparticles were prepared. For these two batches (FHA-1 and FHA-2 in Table 2 below) the polymer solution was 4 % PLGA in 20 ml DCM and the antigen solution was 0.87 µg FHA in 2 ml water containing no PVA. The first water-in-oil emulsion was poured into 80 ml aqueous PVA (3 % PVA) to form the water-oil-water emulsion. The characteristics of these two batches are given in Table 2 below. FHA-1 and FHA-2 were pooled (the pooled microparticles are labelled FHA-3 in Table 2) for antigen release determination and i.p. protection studies (see Example 7 below). SEM



analysis showed the FHA-1 and FHA-2 microparticles to be smooth and spherical in nature with at least 50 % of the particles less than 5 microns in diameter.

Table 2					
Example No.	Loading (mg/mg)	% EE	D50% (μm)	1 hr (%)	24 hr (%)
FHA-1	0.94	87	3.0	•	•
FHA-2	1.09	100	4.3	•	*
FHA-3*	-	-	-	25	49

5

#### Example 4

##### Preparation of antigen entrapped or encapsulated nanoparticles

An aqueous solution (A) of a polymer, surface active agent, surface stabilising or modifying agent or salt, or surfactant preferably a polyvinyl alcohol (PVA) or derivative with a % hydrolysis 50 - 100% and a molecular weight range 500 - 500,000, most preferably 80-100% hydrolysis and 10,000-150,000 molecular weight, is introduced into a vessel. The mixture (A) is stirred under low shear conditions at 10- 2000 rpm, preferably 100-600 rpm. The pH and/or ionic strength of this solution may be modified using salts, buffers or other modifying agents. The viscosity of this solution may be modified using polymers, salts, or other viscosity enhancing or modifying agents.

A polymer, preferably poly(lactide-co-glycolide), polylactide, polyglycolide or a combination thereof or in any enantiomeric form is

dissolved in water miscible organic solvents to form organic phase (B). Most preferably, a combination of acetone and ethanol is used in a range of ratios from 0:100 acetone: ethanol to 100: 0 acetone: ethanol depending upon the polymer used. Additional polymer(s), peptide(s)  
5 sugars, salts, natural/biological polymers or other agents may also be added to the organic phase (B) to modify the physical and chemical properties of the resultant particle product.

An antigen or bioactive substance may be introduced into either the aqueous phase (A) or the organic phase (B). The organic phase (B)  
10 is added into the stirred aqueous phase (A) at a continuous rate. The solvent is evaporated, preferably by a rise in temperature over ambient and/or the use of a vacuum pump. The particles are now present as a suspension (C).

The particles (D) are then separated from the suspension (C) using  
15 standard colloidal separation techniques, preferably by centrifugation at high 'g' force, filtration, gel permeation chromatography, affinity chromatography or charge separation techniques. The supernatant is discarded and the particles (D) re-suspended in a washing solution (E) preferably water, salt solution, buffer or organic solvent(s). The particles  
20 (D) are separated from the washing liquid in a similar manner as previously described and re-washed, commonly twice.

The particles may then be dried. Particles may then be further processed for example, tabletted, encapsulated or spray dried.

The release profile of the particles formed above may be varied from immediate to controlled or delayed release dependent upon the formulation used and/or desired.

Antigen loading may be in the range 0-90% w/w.

5 Specific examples include the following:

A PTd (168 µg/ml) or FHA (264 µg/ml) solution was first dispersed in a PVA (mwt = 13000-23000; 98% hydrolysis) solution while stirring at 400 rpm with the temperature set at 25°C. A polymer solution (prepared by dissolving PLGA; 50:50; either RG504 or  
10 RG504H supplied by Boehringer Ingelheim into the organic phase) was added slowly into the aqueous phase to form coacervates that hardened following evaporation of the organic solvent. The nanoparticles were then recovered by centrifugation at 15,000 rpm for 30 minutes and washed three times with autoclaved deionised water. The wet pellet was  
15 allowed to dry at ambient temperature under a vacuum. Batches having a theoretical loading of 0.3% PTd (RG504H and RG504 polymer), 0.2% FHA (RG504H and RG504 polymer) were prepared according to Table 3.

Table 3					
Batch	5% w/v PVA soln.	PLGA polymer (g)	Acetone (ml)	Ethanol (ml)	antigen (ml)
0.3% PTd	546.4	2.991	67.5	7.5	53.6
0.2% FHA	577.3	2.994	67.5	7.5	22.7

Scanning microscopy was employed to assess the nanoparticle morphology and size. The nanoparticles were mounted onto SEM stubs, sputter coated using an Emitech K550 sputter coater set at 25 mA for 3 minutes and scanned using a Leica Cambridge S360. Micrographs were taken at magnifications of 500 – 20,000x. Particle size assessment by SEM was carried out by dividing the micrographs at the 15,000 magnification into different fields and counting the number of particles greater and less than 600 nm and 500 nm. The SEM analysis showed that for both the PTd-PLGA and FHA-PLGA nanoparticles were approximately spherical in shape with smooth surfaces. At least 50 % of the particles were less than 600nm at the 15k magnification, although there was some evidence of aggregation.

Antigen loading was determined by measuring the total protein content of the nanoparticles using a BCA protein assay as described in Example 1. The nanoparticles prepared according to the present example were found to have the potencies and encapsulation efficiencies as given in Table 5.

Table 4		
Batch	Potency (µg/ml)	Encapsulation efficiency (%)
0.3% PTd –RG504H	1.3	43.3
0.2% FHA – RG504H	0.9	45.0
0.3% PTd –RG504	1.3	43.3
0.2% FHA – RG504	1.0	50.0

The *in vitro* release of antigen from the loaded particles was determined by suspending 50 mg of nanoparticles in 10 ml PBS, pH 7.4, containing 0.02% w/v sodium azide in glass tubes and incubating at 37°C. At predetermined time intervals, a 3 ml sample was removed and the total protein released was determined by the BCA protein assay described above. PTd-PLGA formulations showed a large burst effect of approximately 45% in the first hour followed by a very gradual release up to 55% at 24 hours. In comparison, FHA-PLGA formulations showed a much lower burst release of 14% at 1 hours up to 18% after 24 hours.

#### Example 5

##### Immune response upon i.p. administration of KLH-PLGA microparticles to balb/c mice

The immunogenicity of KLH entrapped in biodegradable microparticles was assessed in mice following parenteral (i.p.) administration and compared with the same antigen in solution (phosphate buffered saline: PBS) or adsorbed to alum. Further control groups included KLH in solution with empty PLGA microparticles, empty PLGA microparticles alone or PBS alone. Microparticles from the two batches of Example 1 were pooled and suspended in PBS at a concentration equivalent to 100 µg of antigen per ml or diluted accordingly for lower doses. Each mouse was immunised with 0.3 ml once or twice at a four week interval and immune responses were assessed 2 weeks after the last immunisation.

Serum and mucosal secretions (lung homogenates) were tested for anti-KLH IgG and IgA antibody levels by ELISA. Systemic cellular immune responses were assessed using spleen from immunised mice. The spleen cells from 4 to 6 individual mice in each experimental group were cultured in triplicate wells of duplicate 96-well microtitre plates with a range of concentrations of antigen (0.16 to 100µg/ml). The mitogens Concanavlin A or PMA and anti-CD3-antibody or medium alone were included as positive and negative controls respectively. After 24 and 72 hours supernatants were removed from one plate and stored at -70°C for cytokine analysis. The levels of interferon  $\gamma$  (IFN- $\gamma$ ) and interleukin-5 (IL-5) were determined by immunoassay as quantifiable markers of induction of antigen-specific T<sub>H</sub>1 and T<sub>H</sub>2 subpopulations respectively. Additionally, the proliferation of T cell cultures were assessed in four day cultures, by [<sup>3</sup>H]-thymidine incorporation.

A single i.p. immunisation with 20 µg KLH entrapped in PLGA microparticles induced potent cellular immune responses with high nanogram levels of IFN- $\gamma$  produced by spleen cells following *in vitro* stimulation with KLH over a wide dose range. Picogram levels of IL-5 were also detected in antigen-stimulated spleen cell supernatants but the levels were comparatively lower than that observed with spleen cells from animals immunised with KLH adsorbed to alum. Overall the responses were polarised to T<sub>H</sub>2 with antigen adsorbed onto alum and to T<sub>H</sub>1 with microencapsulated antigen. Fig. 1 shows the immune response following the second immunisation at four weeks. The levels of IL-5 for the microencapsulated KLH were comparable with those observed with alum, but the production of IFN- $\gamma$  was significantly higher.

Furthermore, potent antigen-specific proliferation was observed in spleen cells from mice immunised with KLH entrapped in PLGA microparticles. The stimulation indices (derived by dividing the response to antigen by the response to medium alone) were significantly  
5 higher than those observed with spleen cells from mice immunised with KLH adsorbed to alum at all antigen doses tested *in vitro*.

Following parenteral immunisation with microencapsulated KLH, the levels of KLH-specific IgG in serum were significantly higher than those generated with the soluble antigen and were equal to or greater  
10 than that induced with alum absorbed antigen. Co-injection with empty PLGA also appeared to significantly boost the antibody responses to soluble antigen. Although each of the animals immunised with 20µg of soluble KLH by the i.p. route generated detectable antibody response, the titres were more than 10 fold higher when the antigen was combined  
15 with empty PLGA microparticles prior to immunisation. These findings suggest that the  $T_H2$  and antibody, but not the  $T_H1$  response was significantly boosted following co-injection of empty microparticles with soluble antigen, whereas  $T_H1$  responses are enhanced with the microencapsulated antigen.

20 These results demonstrate that the entrapment of soluble antigen KLH in PLG microparticles significantly enhanced T cell proliferative responses over that observed with soluble antigen and was comparable to that observed with alum adsorbed antigen by the i.p. route. Moreover, encapsulation of the antigen in PLGA appears to favour the induction of  
25  $T_H1$  cells.

### Example 6

#### Immune response upon i.p. administration of PTd-PLGA microparticles to balb/c mice.

Similarly to the immunisation regimen of Example 5, batch PTd-1  
5 of Example 2 was used in a preliminary parenteral immunisation study in which mice were immunised with two i.p. inoculations of 5 µg PTd entrapped in PLGA microparticles, adsorbed to alum or in solution combined with empty PLGA microparticles. Control mice were immunised with PBS alone or with empty PLGA microparticles alone.  
10 Antibody responses were detected by ELISA two weeks after administration of the second dose. Potent anti PTd-IgG titres were observed after each of the two immunisations, with PTd-PLGA titres on the order of  $1 \times 10^6$ , comparable to those obtained with alum, being obtained after the second immunisation. No responses were seen in mice  
15 exposed to empty PLGA microparticles. Surprisingly, PTd in solution gave responses in 3/5 mice; these responses are unlikely to be sustained over time compared to PTd-PLGA or PTd-alum and they were not seen in the first immunisation. The effects of PTd in solution were enhanced in the presence of empty PLGA.

20 Fig. 2 shows the cytokine analysis after the first i.p. immunisation, demonstrating a dominant  $T_H1$  cell-mediated immune response to PTd-PLGA. Upon re-exposure to pertussis, a high level of IFN- $\gamma$  ( $T_H1$ ) and only modest levels of IL-5 ( $T_H2$ ) were seen in the spleen cell cultures from animals previously immunised with PTd-PLGA. Cells re-exposed  
25 to pertussis following a PTd-alum immunisation gave relatively strong IFN- $\gamma$  and IL-5 production.



### Example 7

#### Pertussis challenge study following i.p. immunisation of balb/c mice with the antigen combination PTd +FHA

Groups of 20 balb/c mice were immunised i.p. with 5µg each of  
5 PTd and FHA entrapped in PLGA microparticles (using PTd-6 of  
Example 2 and FHA-3 of Example 3) or adsorbed to alum. The control  
group received empty PLGA microparticles. The ability of PLGA-  
entrapped antigen to protect against *B. pertussis* was examined in a  
respiratory challenge model. Briefly, following two doses of antigen,  
10 four weeks apart, a respiratory *B. pertussis* infection was initiated in 16  
mice per experimental group by aerosol challenge of approximately  $2 \times 10^{10}$  cfu/ml (approximately  $10^4 - 10^5$  cfu per mouse lung) two weeks  
after the second immunisation. The mice were sacrificed at different  
time points over a two-week period and lung homogenates were cultured  
15 and examined after 5 days culture for the number of colony forming  
units (CFU). Four mice from each group were sacrificed prior to  
challenge to test immune responses on the day of challenge.

The results from the CFU counts 2 hours and 3, 7, 10 and 14 days  
after challenge, which are shown in Fig. 3, reveal a high level of  
20 protection with both PLGA microparticle entrapped and alum adsorbed  
antigens. These treatments provided clearance of *B. pertussis* by the third  
day post challenge following challenge 6 weeks after immunisation. The  
potency index which compares the counts for the test "vaccine" with the  
un-immunised control group were 88.8 and 88.4 for the PTd + FHA in  
25 PLGA and PTd + FHA adsorbed to alum respectively. These potency

indices equal or exceed the levels of potency for commercial acellular vaccines, including 3 and 5 component vaccines.

The immune responses on the day of challenge revealed very strong anti-PT antibody responses with the PLG entrapped antigens as shown in Fig. 4. The end point titres were  $\log_{10}$  5.8 for the PLGA group and 5.0 for the alum group. The anti-FHA antibody titres were of the order of 5.0 for both alum and PLGA groups.

Results of the CMI studies revealed positive T cell proliferative responses against inactivated PT and FHA in all mice immunised with PTd and FHA microencapsulated in PLGA or adsorbed to alum. The T cell responses against PT were stronger in the PLGA group, whereas the responses to FHA were stronger in the alum group. Fig. 5 shows the corresponding cytokine analysis from splenic T cells following parenteral immunisation with 5 $\mu$ g each of PTd and FHA entrapped in PLGA microparticles ( $T_H1$  polarisation) and 5  $\mu$ g each of PTd and FHA adsorbed onto alum (mixed  $T_H1/T_H2$  responses). These results confirm that as in the case of KLH entrapped in PLGA, PTd entrapped in PLGA and FHA entrapped in PLGA, entrapment of PTd and FHA together in PLGA polarises the immune response towards  $T_H1$  after i.p. delivery. In the case of alum, a mucosal or exclusive  $T_H2$  result is found.

### Example 8

#### Pertussis challenge study following i.p. immunisation of balb/c mice with the antigen combination PTd +FHA (reduced dose)

Groups of 20 balb/c mice were immunised parenterally (i.p.) at week 0 and at week 4 with 1 $\mu$ g each of PTd and FHA entrapped in

PLGA microparticles; 1 µg each of PTd and FHA adsorbed to alum; 1 µg of PTd entrapped in PLGA microparticles or 1 µg FHA entrapped in PLGA microparticles. The control group received empty PLGA microparticles. The ability of PLGA-entrapped antigen (low dose) to  
5 protect against *B. pertussis* was examined in the respiratory challenge model as described in Example 7. The mice were sacrificed at different time points over a two-week period after the aerosol challenge and lung homogenates were cultured and examined after 5 days culture for the number of colony forming units (CFU). Four mice from each group  
10 were sacrificed prior to challenge to test immune responses on the day of challenge.

The results from the CFU counts 2 hours and 3, 7, 10 and 14 days after challenge reveal a high level of protection with 1 µg of FHA and PTd either microencapsulated in PLGA or adsorbed to alum as shown in  
15 Fig. 7. Both of these treatments provide substantial clearance of *B. pertussis* by the third day post challenge following challenge 6 weeks after immunisation.

The cytokine data demonstrates significant polarisation to T<sub>H</sub>1 for the groups treated with FHA and PTd entrapped in PLGA, with PTd  
20 entrapped in PLGA and with FHA entrapped in PLGA while a mixed T<sub>H</sub>1/T<sub>H</sub>2 response is seen for the group treated with FHA and PTd adsorbed to alum. Figure 6 shows the cytokine analysis for FHA entrapped in PLGA microparticles, demonstrating the T<sub>H</sub>1 polarisation of this formulation. The control group produced little response in the T  
25 cells.

ELISA antibody titres for the mice in the five treatment groups were evaluated 2 weeks after the second immunisation, which occurred at week 4. Table 3 presents the mean (SD) serum IgG titres for each group of 4 mice. The results show that the anti-PT antibody titres are not significantly different between the different groups that received formulations that included PTd. However, the anti-FHA antibody levels are significantly stronger in the mice that received alum adsorbed antigens. The levels were about 10 fold lower in the mice that received FHA entrapped in PLGA or FHA and PLGA entrapped in PLGA microparticles.

Table 5		
Immunogen	Anti-PT	Anti-FHA
PTd-PLGA	5.05 (0.48)	<1.00
PTd/FHA-PLGA	4.97 (0.32)	4.54 (0.89)
PTd/FHA-alum	5.20 (0.24)	5.44 (0.16)
FHA-PLGA	<1.00	4.47 (0.94)
Empty-PLGA	<1.00	<1.00

#### Example 9

Pertussis challenge study following i.p. immunisation of balb/c mice with the antigen combination PTd +FHA (delayed challenge)

Three groups of 20 balb/c mice were immunised parenterally (i.p.) at week 0 and at week 4 with 5µg each of PTd and FHA entrapped in PLGA microparticles and 5 µg each of PTd and FHA adsorbed to alum and a control group (empty PLGA microparticles). The ability of

PLGA-entrapped antigen to protect against *B. pertussis* was examined in the respiratory challenge model. Following two doses of antigen, four weeks apart, a respiratory *B. pertussis* infection was initiated in 16 mice per experimental group by aerosol challenge at week 12. The mice were  
5 sacrificed at different time points over a two-week period after the aerosol challenge and lung homogenates were cultured and examined after 5 days culture for the number of colony forming units (CFU). Four mice from each group were sacrificed prior to challenge to test immune responses on the day of challenge.

10 The results of the cytokine analysis at the 12 week time point are consistent with those reported above for analysis at the 6 week time point, showing a polarisation of the T cell response to type 1 with PTd and FHA entrapped in microparticles and to type 2 with alum adsorbed antigens. Overall, these results reveal persistence, and perhaps even  
15 further polarisation, of the  $T_H1$  response after immunisation with antigen entrapped in PLGA microparticles versus alum.

As shown in Fig. 8, the results from the CFU counts 2 hours and 3, 7, 10 and 14 days after challenge reveal a high level of protection with 5 µg of FHA and PTd either microencapsulated in PLGA or adsorbed to  
20 alum. Both of these treatments provide clearance of *B. pertussis* by the third day post challenge following challenge 12 weeks after immunisation.

### Example 10

#### Immune response upon parenteral administration (i.p., s.c., i.m.) of PTd-PLGA and FHA-PLGA microparticles to balb/c mice

Seven groups of 5 balb/c mice were immunized by three different  
5 parenteral routes at week 0 and at week 4 with 1 µg each of PTd and  
FHA in either saline solution or entrapped in PLGA microparticles  
manufactured similarly to those of Examples 2 and 3 ( PTd loading =  
1.42 µg/mg; FHA loading = 1.22 µg/mg; 1.52 mg particles per dose) as  
follows:

- 10 Treatment A: PTd + FHA in solution intraperitoneal (i.p.)
- Treatment B: PTd + FHA in solution subcutaneous (s.c.)
- Treatment C: PTd + FHA in solution intramuscular (i.m.)
- Treatment D: PTd + FHA entrapped in PLGA intraperitoneal (i.p.)
- Treatment E: PTd + FHA entrapped in PLGA subcutaneous (s.c.)
- 15 Treatment F: PTd + FHA entrapped in PLGA intramuscular (i.m.)
- Treatment E: Saline only (control)

The i.p. immunisations were administered in 0.3 ml, the s.c.  
immunisations (on the back) in 0.2 ml and the i.m. immunisation at two  
sites in 0.1 ml.

- 20 Immune responses to these treatments were assessed two weeks  
subsequent to the second immunisation at week 6. Individual spleen cell  
preparations from mice per experimental group were tested for antigen-  
induced proliferation and cytokine production. Serum samples (week 6)  
from individual mice were assessed over an 8-fold dilution range for  
25 anti-PT and anti-FHA IgG.

Analysis of the serum IgG responses revealed clear effects due to the route of administration on the antibody titres, with striking differences between soluble and PLGA entrapped antigen. The s.c. route generated slightly weaker anti-PT antibody response with both soluble  
5 and PLGA entrapped antigens (end-point log titres of ~3.5 and 3.7, respectively). The anti-FHA titres were also lowest when soluble and PLGA-entrapped antigens were given by the s.c. route (end-point log titres of 1.8 and 0.4, respectively). However, very strong anti-PT and anti-FHA responses induced with the PLGA microparticle entrapped  
10 antigens were observed after i.p. immunisation (end-point log titres of ~4.5 and 2.7, respectively). In contrast, immunisation by the i.m. route induced the strongest IgG responses with the antigens in solution (end-point anti-PT and anti-FHA log titres were 4.3 and 3.8 for i.m. solution).

Overall, the anti-PT responses were strongest with the PLGA  
15 entrapped antigens by the i.p. route, whereas the strongest anti-FHA responses were observed with antigens in solution by the i.m. route. These results are consistent with the increased immunogenicity of particulate antigens in the peritoneal cavity, a site rich in phagocytic APC and the slower clearance of soluble antigen administered by the  
20 i.m. route.

T cell proliferative responses against inactivated PT and FHA shows that the strongest responses are observed in mice that received microencapsulated or soluble PTd and FHA by the s.c. routes.

Analysis of the cytokine production from spleen cells showed that  
25 all of the immunogens induced potent antigen-specific T cell responses but also revealed striking differences between administration of antigens

entrapped in PLGA or in solution by different parenteral routes. Overall, the antigens entrapped in PLGA induced a T cell response which was polarised to the  $T_H1$  subtype following any route of parenteral immunisation, whereas the response was more polarised to  $T_H2$  with the antigen in solution.

The best T cell priming with the soluble antigens was observed with the i.m. route followed by s.c., with the poorest results observed for the i.p. route, especially for IL-5 producing cells. Potent  $T_H2$  cytokine production was induced with the soluble antigens given by the i.m. route; the levels of FHA-induced IL-5 exceed 2000 pg/ml for spleen cells in 4 of 5 mice. In contrast, as shown in Fig. 9 for i.m. administration, analysis of the cytokine production following parenteral administration of PLGA microencapsulated antigen to mice revealed that the i.m. route induced IFN- $\gamma$  production by each of the mice in response to each of the antigen preparations tested whereas IL-5 production was weak or undetectable. This was exactly the pattern seen for the i.p. route as described in Figs. 1, 5 and 6. However, the responses were less polarised to  $T_H1$  with PLGA microencapsulated antigens administered by the s.c. route; the IFN- $\gamma$  levels were lower and more inconsistent and significant IL-5 responses were detected in 3 of 5 mice. The finding that the i.m route results in potent  $T_H2$  priming with soluble antigen but  $T_H1$  priming with PLGA entrapped antigen is new and highly significant.

Similarly to the immunisation regimen given above, a repeat of the above parenteral route study was undertaken in which groups of balb/c mice were immunized at week 0 and week 4 with inoculations of 1  $\mu$ g of each of the antigens according to the following treatments:



- Treatment 1: PTd + FHA in solution subcutaneous (s.c.)  
Treatment 2: PTd + FHA in solution intramuscular (i.m.)  
Treatment 3: PTd + FHA entrapped in PLGA subcutaneous (s.c.)  
Treatment 4: PTd + FHA entrapped in PLGA intramuscular (i.m.)  
5 Treatment 5: empty PLGA subcutaneous (s.c.) (control)

The ability of these s.c. and i.m. treatments to protect against *B. pertussis* was examined in the respiratory challenge model as described in Example 7. The results from the CFU counts reveal a high level of protection from Treatments 3 and 4 (microparticles injected s.c. and i.m.).  
10 Both of these treatments, as well as that of Treatment 2 (antigens in solution, i.m.), provide substantial clearance of *B. pertussis* by the third day post challenge following challenge 2 weeks after the second immunisation. In contrast, neither Treatment 5 (empty PLGA, s.c.) or Treatment 1 (antigens in solution, s.c.) show clearance at the third day  
15 post challenge.

#### Example 11

##### Immune response upon parenteral administration of PTd-PLGA and FHA-PLGA nanoparticles to balb/c mice

The immunogenicity of coacervate formulations of PTd, FHA and  
20 the combination of PTd and FHA entrapped in biodegradable PLGA nanoparticles was assessed in mice following parenteral (i.p.) administration and compared to the administration of PTd and FHA in solution and empty PLGA nanoparticles. Six groups of mice were immunised i.p. with FHA and/or PTd formulations according to Example

4 (5 µg FHA and/or PTd in 0.3 ml deionised water) or with empty PLGA nanoparticles (control) as follows:

- Treatment A: empty PLGA nanoparticles
- Treatment B: PTd and FHA in solution
- 5 Treatment C: PTd -PLGA (RG504) nanoparticles
- Treatment D: FHA-PLGA (RG504) nanoparticles
- Treatment E: PTd-PLGA (RG504) + FHA-PLGA (RG504)  
nanoparticles
- 10 Treatment F: PTd-PLGA (RG504H) + FHA-PLGA (RG504H)  
nanoparticles

Each mouse was dosed with two i.p. inoculations at weeks 0 and 4; immune responses were tested 2 weeks after the second immunisation (week 6).

Overall, very potent antibody responses were generated with  
15 antigens entrapped in these PLGA coacervate nanoparticles, with mean anti-PT serum IgG endpoint log titres of 4.3 and mean anti-FHA serum endpoint log IgG titres of 4.6. The anti-FHA antibody titres were modestly stronger with entrapped FHA compared to FHA in solution; however, the anti-PT titres for the entrapped and solution formulations  
20 were not significantly different. Formulations containing both PTd and FHA entrapped nanoparticles did not raise significantly different antibody responses compared to those generated by either entrapped antigen alone. The responses are almost identical using the two different PLGA polymers.

As shown in Fig. 10, in contrast to the  $T_H1$  polarisation found upon i.p. immunisation with microparticulate entrapped antigens discussed above, the most striking feature of the antigen-specific spleen cell cytokine production was the strong polarisation of the response to  $T_H2$  for all these nanoparticulate formulations. High levels of IL-5 were produced by spleen cells stimulated *in vitro* with FHA (1 or 5  $\mu\text{g/ml}$ ) or inactivated PT (1 or 5  $\mu\text{g/ml}$ ) or killed *B. pertussis*. The only significant antigen-specific IFN- $\gamma$  production observed was against PT and killed *B. pertussis* in mice given PTd entrapped in PLGA.

10 A repeat experiment in which groups of 5 mice were immunised i.p. with PTd + FHA in solution, PTd + FHA in PLGA nanoparticles (formulations as outlined in Example 4) and empty PLGA nanoparticles (control) was undertaken following the same protocol as given above in this example. Spleen cell preparations from 5 mice per leg were tested  
15 individually for antigen-induced proliferation and cytokine production and serum samples from individual mice were assessed over an 8-fold dilution range for anti-PT and anti-FHA IgG.

Again, antibody responses induced with the pertussis antigens entrapped in PLGA nanoparticles were very strong, with end point titres  
20 in the range 4.0 to 5.0. The response to PT was almost one log stronger with the PLGA entrapped antigens when compared with the soluble antigens. The responses to FHA were stronger overall than to PT and there was not a significant difference in the end point titres in sera from mice immunised with soluble or PLGA entrapped antigens.

Strong proliferative T cell responses to FHA and killed bacteria were observed in individual spleen cell preparations from all mice immunised with PTd and FHA either in solution or entrapped in PLGA. There was no significant difference between the two immunogens. Analysis of cytokine production by spleen cells revealed very high levels of IL-5 (in the region of 1500 to 3000 pg/ml) and very modest levels of IFN- $\gamma$  in response to FHA in all mice immunised with PTd and FHA, either in solution or entrapped in PLGA. Figure 10 shows the cytokine data from the coacervated nanoparticles. The responses to inactivated *B. pertussis* were somewhat lower but were still in the region of 500 pg/ml compared with levels less than 15 pg/ml in control mice immunised with empty PLGA nanoparticles. Therefore, the overall pattern is a polarisation towards a T<sub>H</sub>2 response by administration of soluble antigens or antigens entrapped in coacervated nanoparticles.

### Example 12

#### Preparation of KLH-PLA microparticles by a spray drying method

A PLA (poly D, L lactide; molecular weight 16,000 solution; i.v. = 0.27 dl/g; supplied by Boehringer Ingelheim, R203) solution in ethylacetate (5 % PLA in 150 ml ethylacetate) was prepared two hours prior to use. The polymer solution was homogenised (at 24,000 rpm) using an IKA Ultra Turrax T25 homogeniser with an S1 head while the KLH antigen solution (62 mg KLH in MES (2-[n-morpholino] ethanesulfonic acid)) was added slowly. The emulsion was cooled on ice and homogenisation was continued for 1 min. The single emulsion

thus prepared was spray dried using a Büchi 191 mini spray drier with continuous stirring using a magnetic stirrer. The following parameters were used in the spray drying step:

Table 6			
Parameter	Value	Parameter	Value
Inlet temperature (°C)	60	Aspirator (%)	100
Outlet temperature (°C)	45	Pump rate* (ml / min.)	5
Flow rate	700 - 800	Pressure (mbar)	- 40

\*Pump rate was set at 25 %, the actual rate of solvent pumped through

5

varied from 5 to 6 ml / min.

The particles were collected immediately from both the collection vessel and the cyclone. The antigen-loaded microparticles were characterised according to the procedures outlined above for the previous examples. The microparticles formed according to the present invention (yield 33%) were found to be smooth and spherical in nature. The loading ( $\mu\text{g}/\text{mg}$ ) was 7.4 with an entrapment efficiency of 91% and a D50% by laser light diffractometry of  $4.6\mu\text{m}$ . The *in vitro* release of KLH was found to be 10% within one hour and 49% on day 23.

15

Similar to the Examples above, mice were immunised with two i.p. inoculations of  $20\mu\text{g}$  KLH either entrapped in PLA microparticles or adsorbed to alum. Titres were obtained when the particles were administered to mice systemically ( $1 \times 10^5$ ) which were comparable with those obtained in the KLH-alum group. Furthermore, the KLH-

PLA particles resulted in a dominant  $T_H2$  response when administered i.p. which is in contrast to that observed in the above examples for KLH-PLGA microparticles in which polarisation was towards the  $T_H1$  type.

Example 13:

5     Preparation of PTd-PLA microparticles by a spray drying method

PTd-PLA microparticles were formed by a spray drying method similar to that of Example 12 with the exceptions that, to prevent phase separation during spray drying, the homogenisation speed was increased to 24,000rpm, the polymer viscosity was increased by using 5% R203  
10     and the w/o emulsion was stirred during spraying. The release profile of the resultant particles was characterised by a marked burst of 50-60% in the first hour followed by a very slow release phase over a three month period of time.

Serum anti-PTd IgG levels were determined in mice immunised  
15     i.p. with 5  $\mu$ g PTd in spray dried PLA microparticles and compared to immunisation with PTd-alum, empty PLA particles mixed with soluble PTd, or PTd in solution. However, no antibody or T-cell responses were obtained in mice immunised systemically with PTd-PLA.

The integrity of PTd, FHA and KLH following either the solvent  
20     evaporation (*see* Examples above) or spray drying processes were examined semi-quantitatively by PAGE gel analysis. More PTd remains intact when extracted from particles prepared by the solvent evaporation method relative to spray dried particles. Thus, the PTd may have been partially degraded during the spray drying process. The data suggest that  
25     while spray-drying is problematic for maintaining antigenic structure in

the case of PTd, this cannot be assumed for less labile antigens and it will therefore need to be assessed on a case by case basis.

Claims: -

1. A method of inducing a  $T_H1$  polarised immune response to an antigen, comprising parenterally administering to a subject microparticles sized such that at least 50% of the microparticles are less than 5  $\mu m$ , the microparticles comprising the antigen entrapped or encapsulated by a biodegradable polymer.
2. The method of Claim 1, wherein the microparticles are sized such that at least 50% of the microparticles are less than 3  $\mu m$ .
3. The method of Claim 1, wherein the biodegradable polymer comprises a copolymer of lactic acid and glycolic acid or enantiomers thereof.
4. The method of Claim 1, wherein the microparticles are formed using a solvent evaporation method.
5. The method of Claim 1, wherein the antigen comprises a *B. pertussis* antigen.
6. The method of Claim 1, wherein the parenteral administration is selected from the group consisting of intraperitoneal administration, subcutaneous administration and intramuscular administration.
7. A method of inducing a  $T_H2$  polarised immune response to an antigen, comprising parenterally administering to a subject nanoparticles sized such that at least 50% of the nanoparticles are less than 600 nm, the nanoparticles comprising the antigen entrapped or encapsulated by a biodegradable polymer.



8. The method of Claim 7, wherein the nanoparticles are sized such that at least 50% of the nanoparticles are less than 500 nm.

9. The method of Claim 7, wherein the biodegradable polymer comprises a copolymer of lactic acid and glycolic acid or enantiomers thereof.

10. The method of Claim 7, wherein the nanoparticles are formed using a coacervation method

11. The method of Claim 7, wherein the antigen comprises a *B. pertussis* antigen.

12. The method of Claim 7, wherein the parenteral administration is selected from the group consisting of intraperitoneal administration, subcutaneous administration and intramuscular administration.

13. A method of inducing a combined T<sub>H</sub>1 and T<sub>H</sub>2 immune response to an antigen, comprising parenterally administering to a subject

- a) the antigen entrapped or encapsulated by a biodegradable polymer to form microparticles sized such that at least 50% of the microparticles are less than 5  $\mu$ m;

in combination with

- b) the antigen entrapped or encapsulated by a biodegradable polymer to form nanoparticles sized

such that at least 50% of the nanoparticles are less than 600 nm.

14. The method of Claim 13, wherein the microparticles are administered simultaneously, separately, or sequentially with the nanoparticles.

15. A vaccine formulation for enhancing the  $T_H1$  immune response to at least one antigen and adapted for parenteral administration comprising a pharmaceutically acceptable carrier and a pharmaceutically effective amount of microparticles sized such that at least 50% of the microparticles are less than 5  $\mu\text{m}$ , the microparticles comprising the at least one antigen entrapped or encapsulated by a biodegradable polymer.

16. The vaccine formulation of Claim 15, wherein the microparticles are sized such that at least 50% of the microparticles are less than 3  $\mu\text{m}$ .

17. The vaccine formulation of Claim 15, wherein the biodegradable polymer comprises a copolymer of lactic acid and glycolic acid and enantiomers thereof.

18. The vaccine formulation of Claim 15, wherein the microparticles are formed using a solvent evaporation method.

19. The vaccine formulation of Claim 15, wherein the at least one antigen comprises a *B. pertussis* antigen.

20. The vaccine formulation of Claim 15, wherein the microparticles comprise at least 2 subpopulations of microparticles, each

subpopulation comprising a different antigen entrapped or encapsulated by a biodegradable polymer.

21. A vaccine formulation for enhancing the  $T_H2$  immune response to at least one antigen and adapted for parenteral administration comprising a pharmaceutically acceptable carrier and a pharmaceutically effective amount of nanoparticles sized such that at least 50% of the nanoparticles are less than 600 nm, the nanoparticles comprising the at least one antigen entrapped or encapsulated by a biodegradable polymer.

22. The vaccine formulation of Claim 21, wherein the nanoparticles are sized such that at least 50% of the nanoparticles are less than 500 nm.

23. The vaccine formulation of Claim 21, wherein the biodegradable polymer comprises a copolymer of lactic acid and glycolic acid and enantiomers thereof.

24. The vaccine formulation of Claim 21, wherein the nanoparticles are formed using a coacervation method.

25. The vaccine formulation of Claim 21, wherein the at least one antigen comprises a *B. pertussis* antigen.

26. The vaccine formulation of Claim 21, wherein the nanoparticles comprise at least 2 subpopulations of nanoparticles, each subpopulation comprising a different antigen entrapped or encapsulated by a biodegradable polymer.

27. A method of providing protective immunity against *B. pertussis*, comprising parenterally administering to a subject a

pharmaceutically effective amount of microparticles sized such that at least 50% of the microparticles are less than 5  $\mu\text{m}$ , the microparticles comprising at least one *B. pertussis* antigen entrapped or encapsulated by a biodegradable polymer.

28. The method of Claim 27, wherein the microparticles are sized such that at least 50% of the microparticles are less than 3  $\mu\text{m}$ .

29. The method of Claim 27, wherein the biodegradable polymer comprises a copolymer of lactic acid and glycolic acid and enantiomers thereof and wherein the microparticles are formed using a solvent evaporation method.

30. The method of Claim 27, wherein the at least one *B. pertussis* antigen is selected from the group consisting of inactivated pertussis toxin (PTd), filamentous hemagglutinin (FHA), pertactin and fimbriae and combinations thereof.

31. A method of providing protective immunity against *B. pertussis*, comprising parenterally administering to a subject a pharmaceutically effective amount of nanoparticles sized such that at least 50% of the nanoparticles are less than 600 nm, the nanoparticles comprising at least one *B. pertussis* antigen entrapped or encapsulated by a biodegradable polymer.

32. The method of Claim 31, wherein the nanoparticles are sized such that at least 50% of the nanoparticles are less than 500 nm.

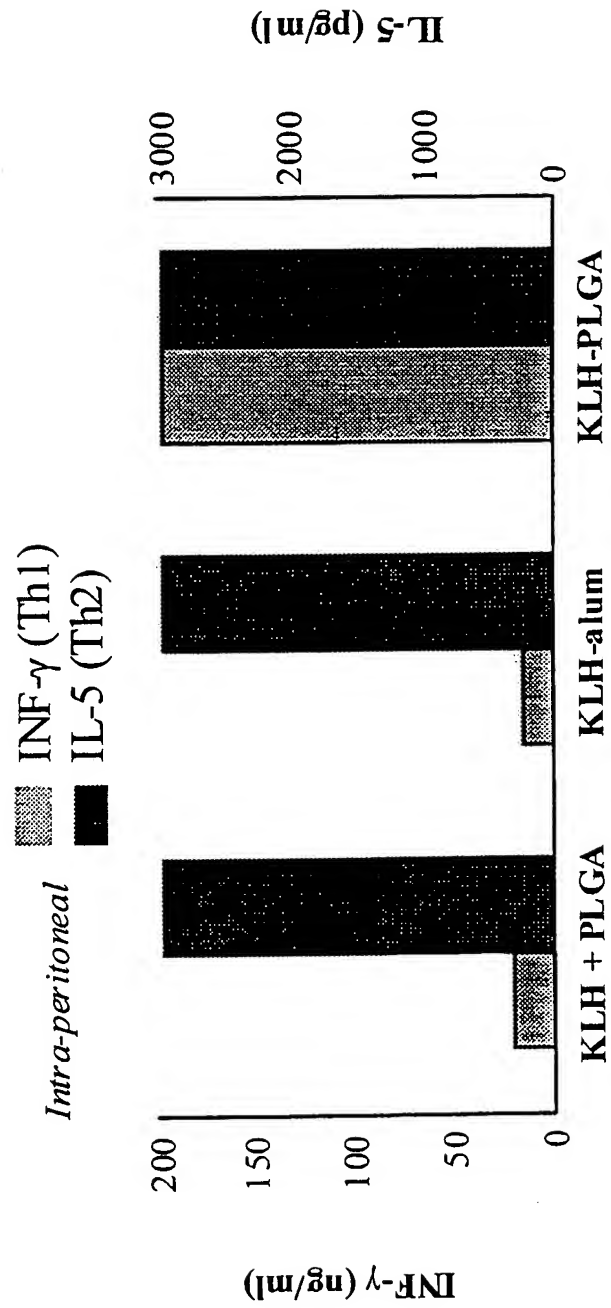
33. The method of Claim 31, wherein the biodegradable polymer comprises a copolymer of lactic acid and glycolic acid and

enantiomers thereof and wherein the nanoparticles are formed using a coacervation method.

34. The method of Claim 31, wherein the at least one *B. pertussis* antigen is selected from the group consisting of inactivated pertussis toxin (PTd), filamentous hemagglutinin (FHA), pertactin and fimbriae and combinations thereof.

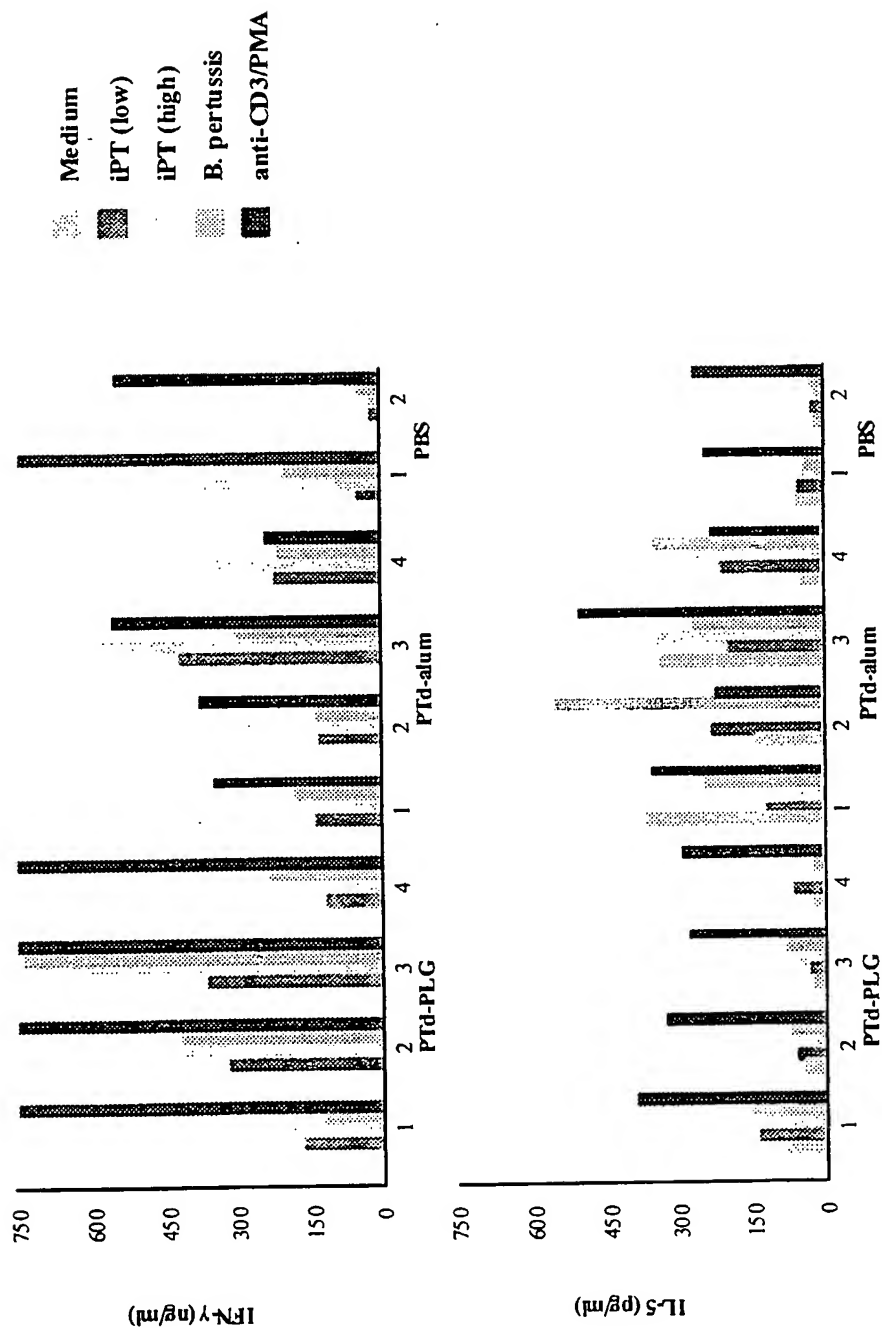
1/10

Fig. 1



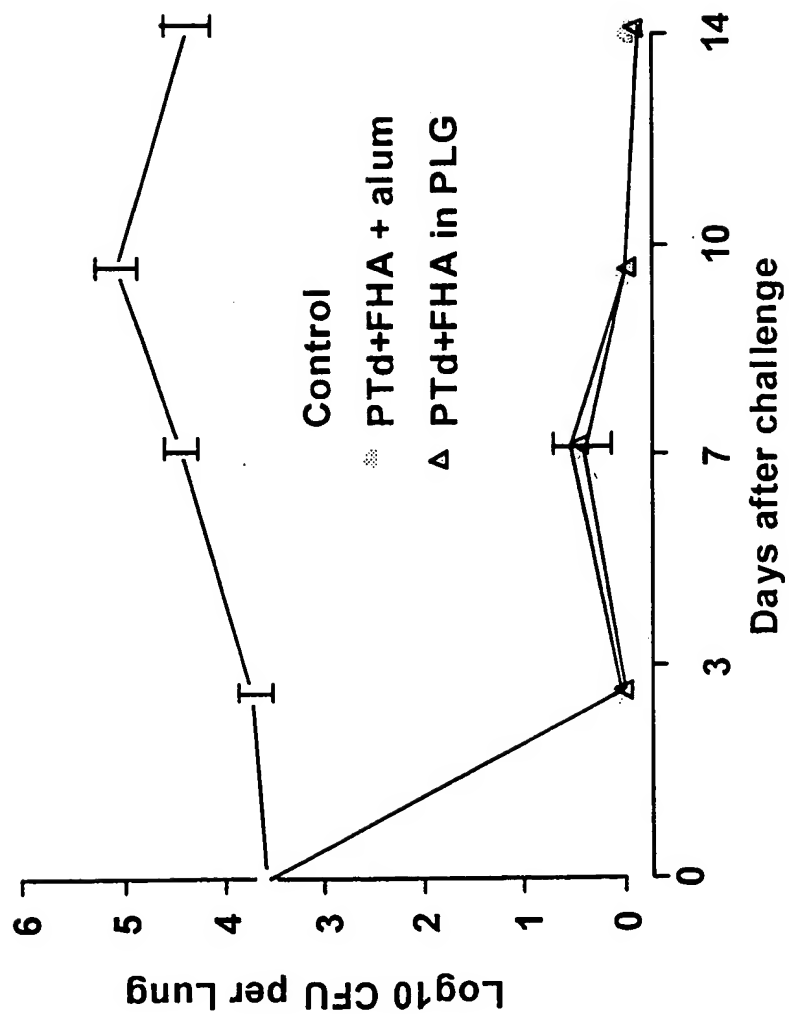
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Fig. 2



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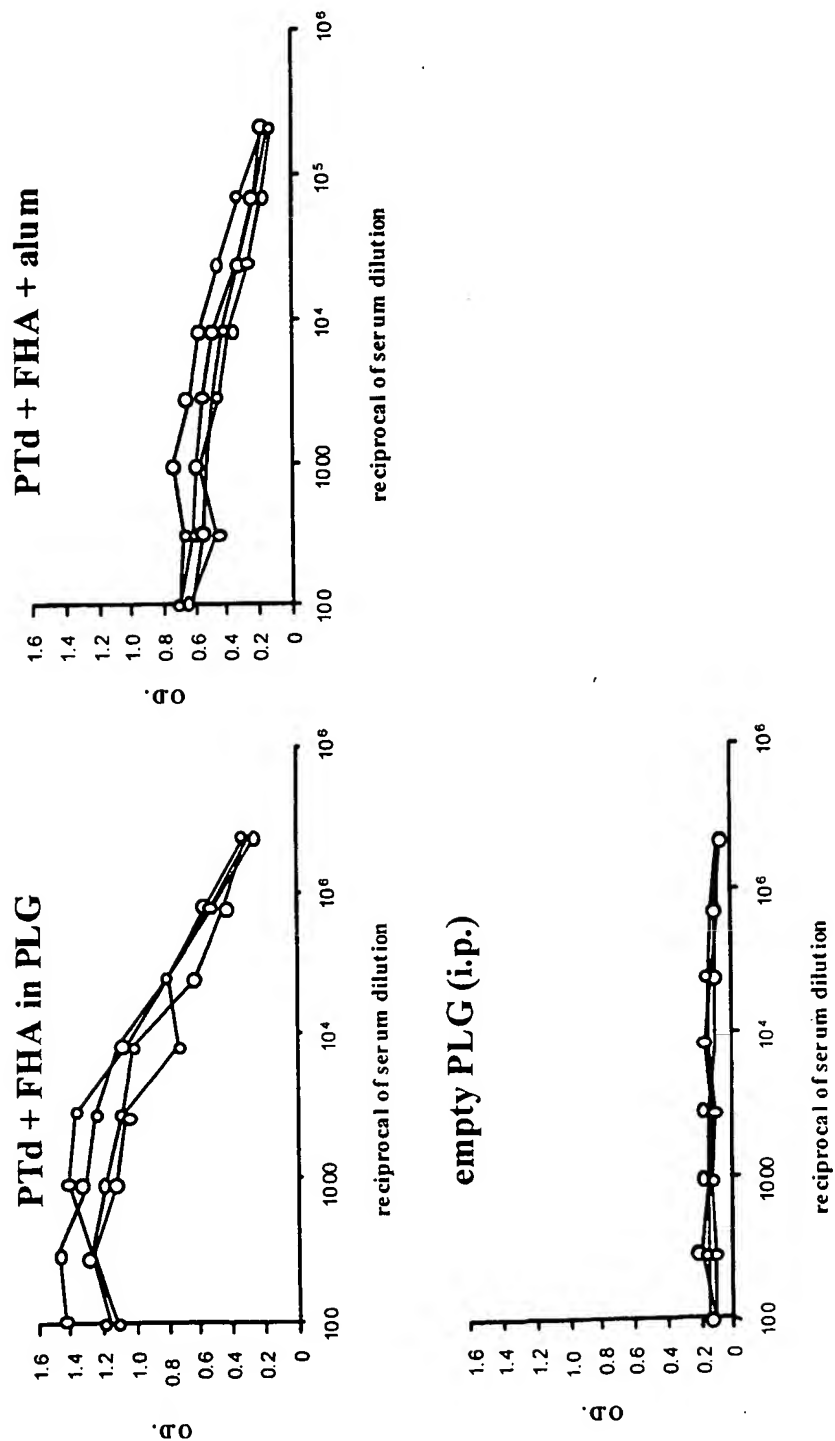
Fig. 3





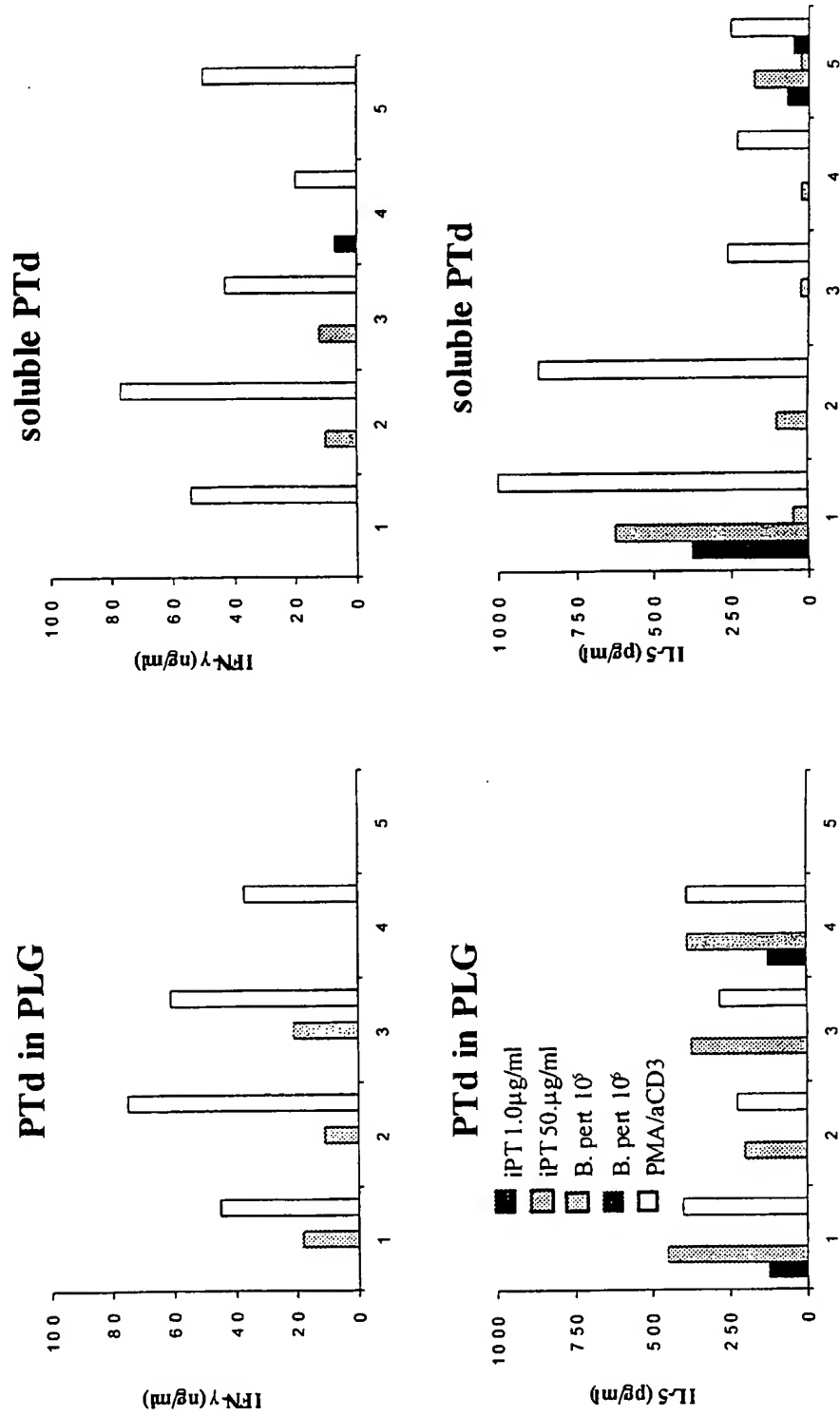
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Fig. 4



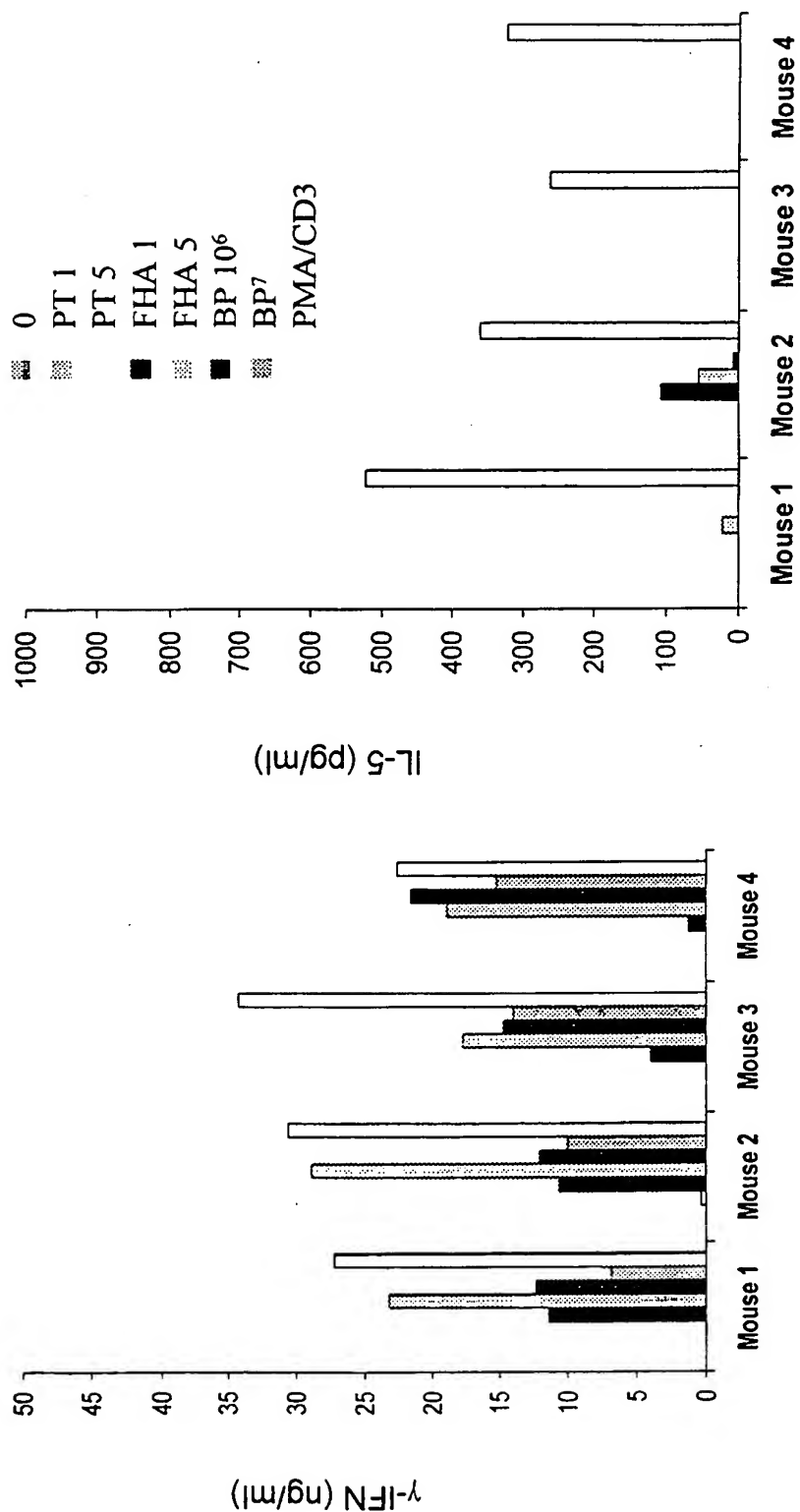
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Fig. 5



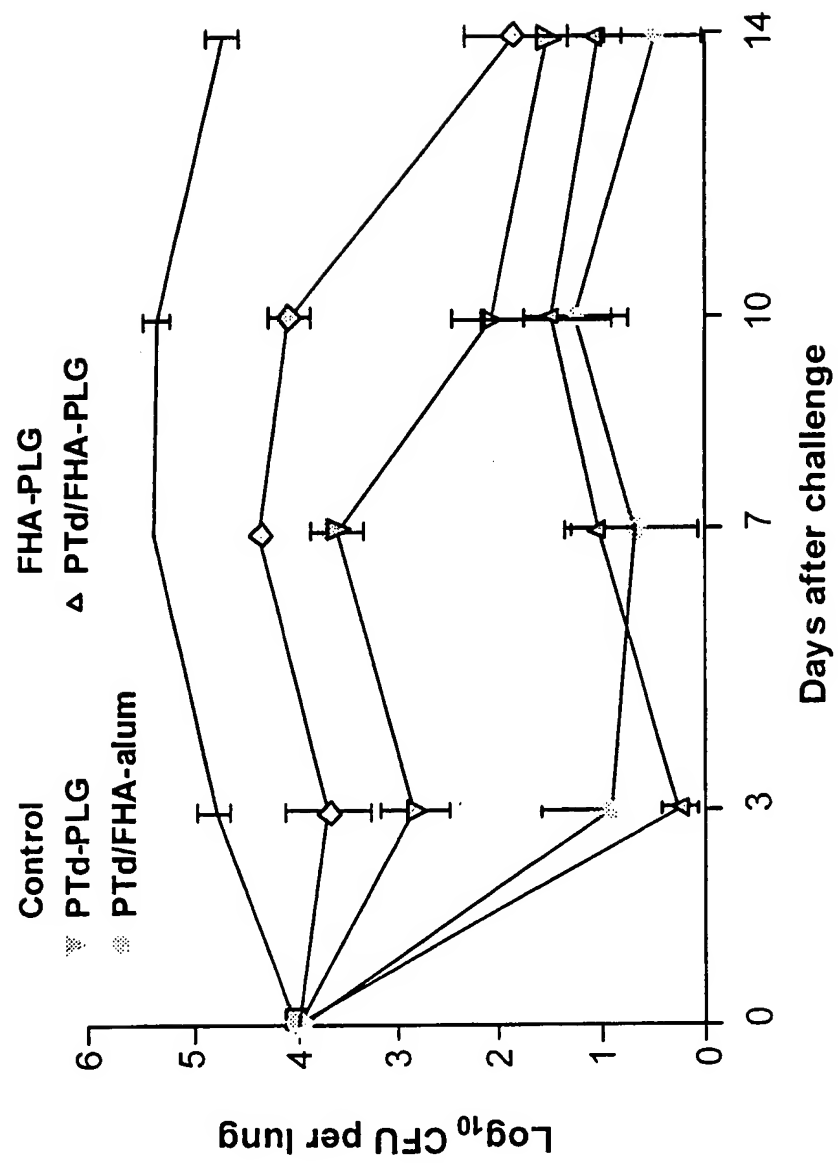
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Fig. 6



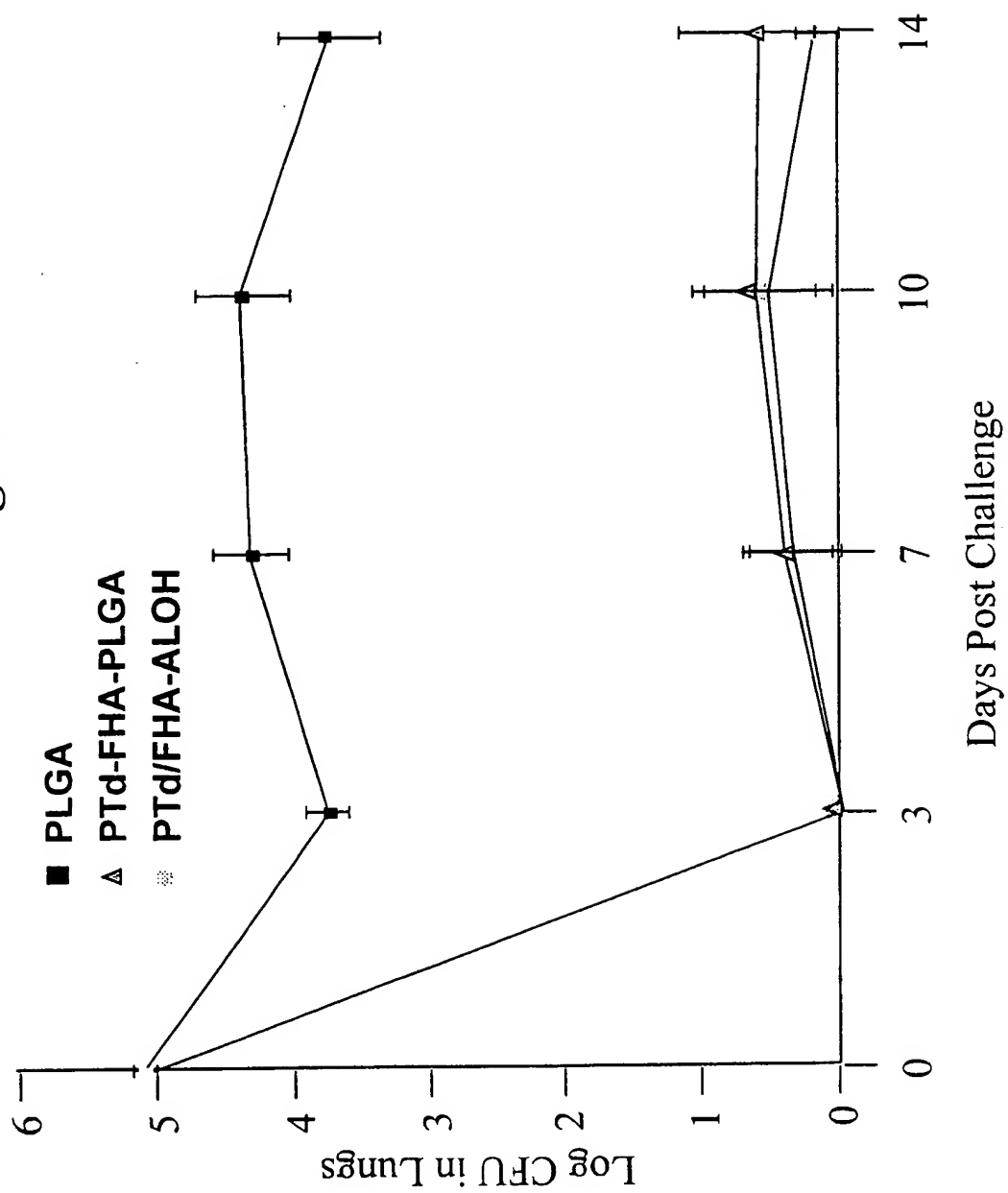
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Fig. 7



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Fig. 8



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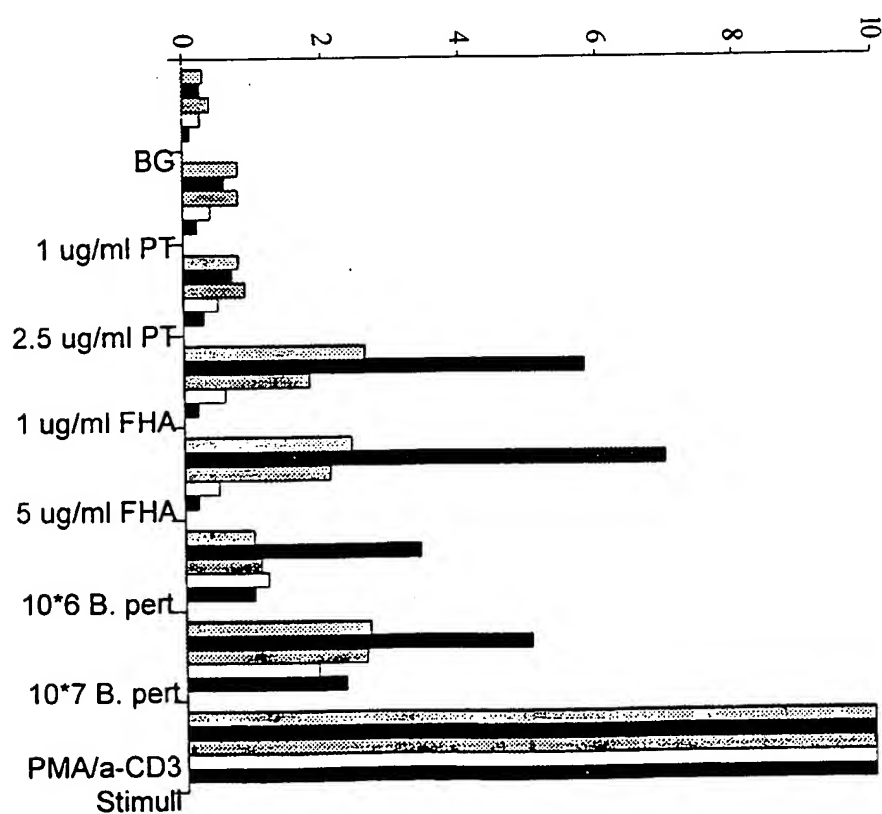
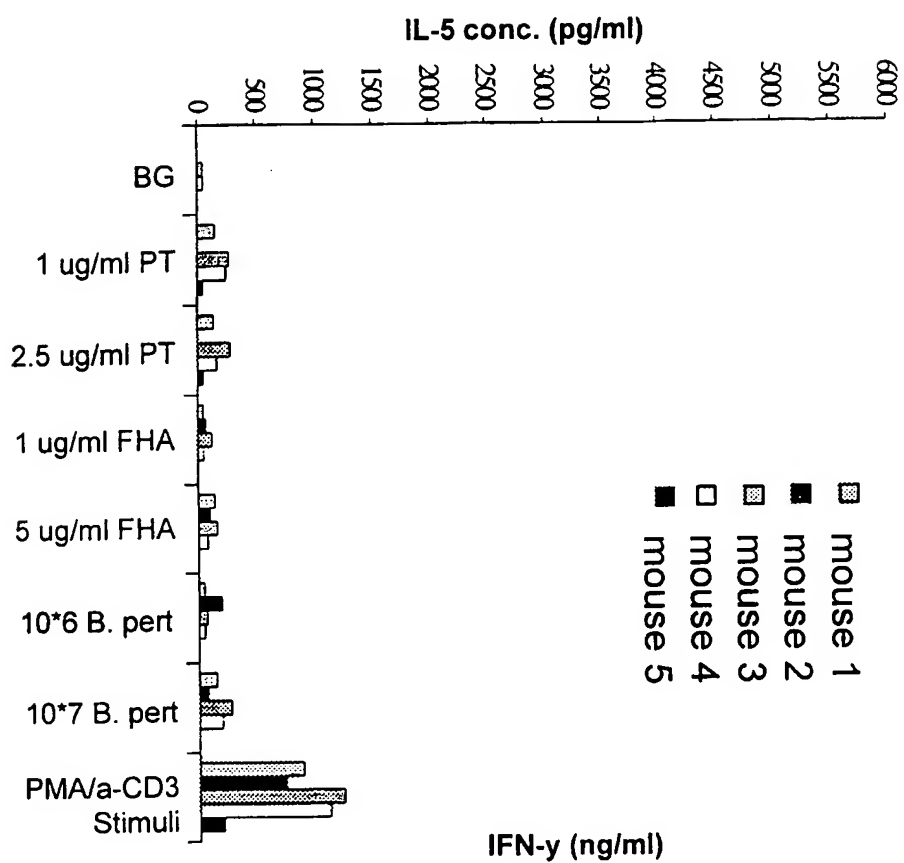
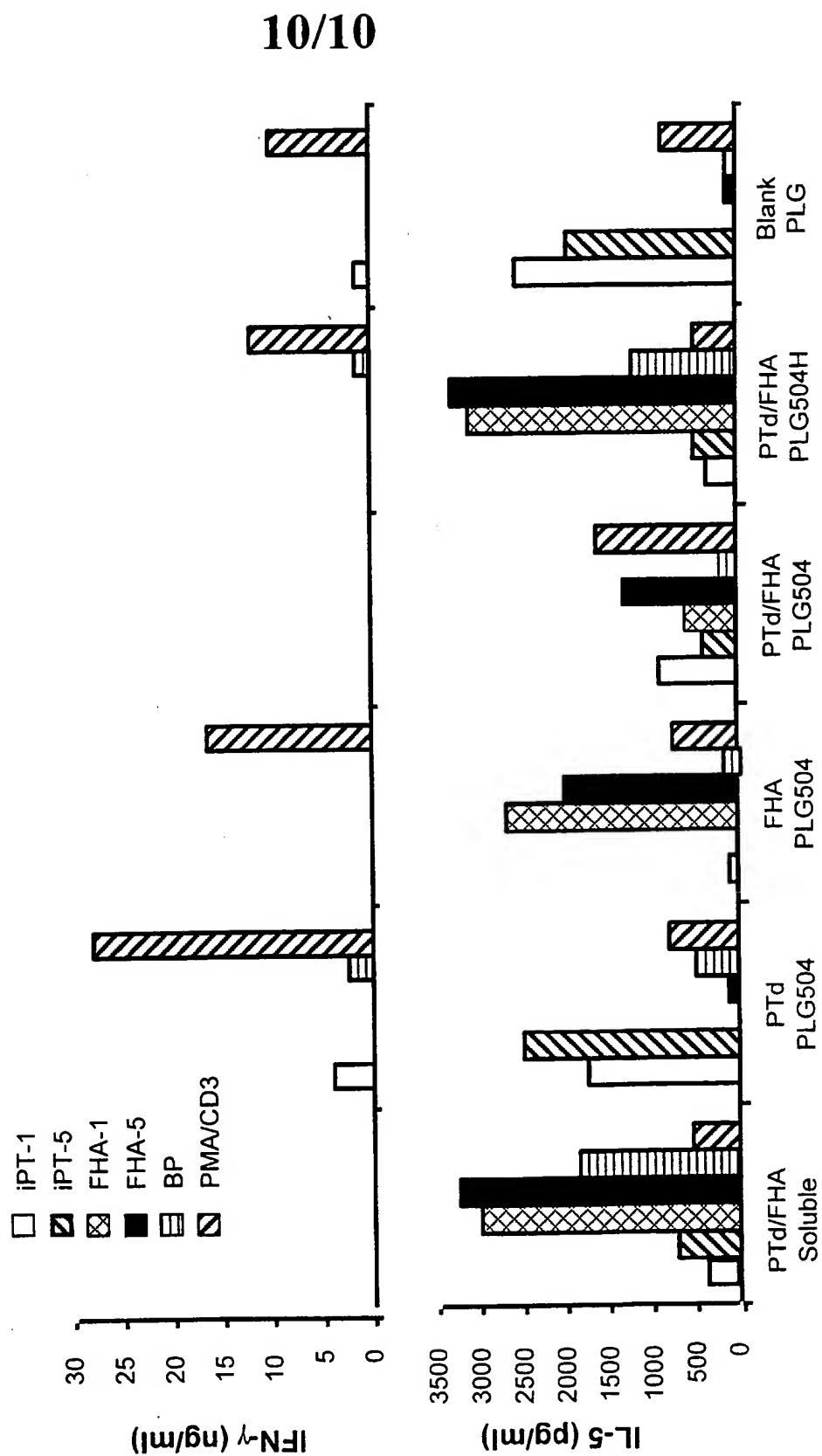


Fig. 9

Fig. 10



# INTERNATIONAL SEARCH REPORT

International Application No

PCT/IE 99/00087

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 A61K39/00 A61K9/16 A61K9/51 A61K39/10 A61K9/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 A61K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>CAHILL ES, ET AL.: "Immune responses and protection against Bordetella pertussis infection after intranasal immunization of mice with filamentous haemagglutinin in solution or incorporated in biodegradable microparticles"</p> <p>VACCINE, vol. 13, no. 5, 1995, pages 455-462, XP004057720 ISSN 0264-410X cited in the application page 456, left-hand column, line 56 -right-hand column, line 44 page 459, left-hand column, line 22 -right-hand column, line 3; figures 6A-C page 460, left-hand column, line 30 -right-hand column, line 2</p> <p>---</p> <p>-/--</p>	<p>1-6, 15-19, 27-30</p>



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

### \* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

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Date of the actual completion of the international search

9 December 1999

Date of mailing of the international search report

27/12/1999

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# INTERNATIONAL SEARCH REPORT

International Application No

PCT/IE 99/00087

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>SHAHIN R, ET AL.: "Adjuvanticity and protective immunity elicited by Bordetella pertussis antigens encapsulated in poly(DL-lactide-co-glycolide) microspheres"</p> <p>INFECTION AND IMMUNITY, vol. 63, no. 4, 1995, pages 1195-1200, XP002124771</p> <p>ISSN 0019-9567</p> <p>cited in the application</p> <p>page 1195, right-hand column, line 20</p> <p>-page 1196, left-hand column, line 18</p> <p>page 1198, right-hand column, line 5 - line 19; table 7</p> <p>page 1199, right-hand column, line 59</p> <p>-page 1200</p> <p>---</p>	<p>15-20, 27-30</p>
X	<p>WO 96 20698 A (UNIV MICHIGAN ; LEVY ROBERT J (US); LABHASETWAR VINOD D (US); SONG)</p> <p>11 July 1996 (1996-07-11)</p> <p>page 6, line 13 -page 7, line 7</p> <p>page 10, line 14 -page 11, line 2</p> <p>page 24, line 19 -page 26, line 4</p> <p>examples 5,10; table 4</p> <p>page 105, line 5 -page 108, line 9; figure 21; examples 21-23</p> <p>claims 1-7,12,19,20,39,40,44</p> <p>---</p>	<p>15-19, 21-25, 27-29, 31-33</p>
X	<p>JONES DH, ET AL.: "Orally administered microencapsulated Bordetella pertussis fimbriae protect mice from B. pertussis respiratory infection"</p> <p>INFECTION AND IMMUNITY, vol. 64, no. 2, 1996, pages 489-494, XP002094244</p> <p>ISSN 0019-9567</p> <p>cited in the application</p> <p>page 490, right-hand column -page 491, left-hand column</p> <p>---</p>	<p>15-19, 27-30</p>
X	<p>NEWMAN KD, ET AL.: "Ovalbumin peptide encapsulated in poly(D,L lactic-co-glycolic acid) microspheres is capable of inducing a T helper type 1 immune response"</p> <p>JOURNAL OF CONTROLLED RELEASE, vol. 54, no. 1, June 1998 (1998-06), pages 49-59, XP004127858</p> <p>ISSN 0168-3659</p> <p>cited in the application</p> <p>paragraphs '02.1!,'02.3!,'0003!; figure 2</p> <p>---</p> <p>-/--</p>	<p>1-4,6, 15-18</p>

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/IE 99/00087

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MOORE A, ET AL.: "Immunization with a soluble recombinant HIV protein entrapped in biodegradable microparticles induces HIV-specific CD8+ cytotoxic T lymphocytes and CD4+ Th1 cells" VACCINE, vol. 13, no. 18, 1995, pages 1741-1749, XP004057378 ISSN 0264-410X cited in the application page 1742, left-hand column, line 43 -right-hand column, line 29 page 1744, left-hand column, line 21 -right-hand column, line 14; figure 4; table 2 ---	1-4, 6, 15-18, 21-24
X	COHEN S AND BERNSTEIN H (EDS.): "Microparticulate Systems for the Delivery of Proteins and Vaccines" 1996, MARCEL DEKKER, INC., NEW YORK, ISBN 0-8247-9753-1 XP002124813 ---	15-18
A	page 51 -page 87 & KISSEL T AND KONEBERG R: "Injectable biodegradable microspheres for vaccine delivery" page 54, line 18 -page 55, line 19; table 1 page 62 -page 67, line 17; figures 5-7 page 72, line 35 -page 79; figure 11 ---	1-34
A	WO 93 21950 A (MEDEVA HOLDINGS BV ;ROBERTS MARK (GB); DOUGAN GORDON (GB)) 11 November 1993 (1993-11-11) cited in the application page 5, line 8 -page 7, line 16 claims 1-3,5,6,9,10 ---	15-20, 27-30
A	REYNOLDS JEF (ED.): "Martindale, The Extra Pharmacopoeia, Thirty-first Edition" 1996, ROYAL PHARMACEUTICAL SOCIETY, LONDON, ISBN 0-85369-342-0 XP002124772 page 1635 -page 1637 & "Pertussis vaccines" page 1636, right-hand column, line 62 -page 1637, left-hand column ---	15-34
P,X	WO 98 58668 A (FARRAR GRAHAM HENRY ;MICROBIOLOGICAL RES AUTHORITY (GB); JONES DAV) 30 December 1998 (1998-12-30) claims 1-6,13-18; example 5 -----	15-20, 27-30

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/IE 99/00087

## Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:  
Remark: Although claims 1-14 and 27-34 are directed to a method of treatment of the human/animal body, the search has been carried out and based on the alleged effects of the composition.
2. ☐ Claims Nos.:  
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/IE 99/00087

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